ELEMENTS

OF

ELECTRO-METALLURGY.

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HONI SOIT QUI MAL Y PENSE
DIEU ET MON DROIT
HONI S QUI MAL Y PENSE
TREU UND FEST

ELEMENTS

OF

ELECTRO-METALLURGY.

BY ALFRED SMEE, F.R.S.

SURGEON TO THE BANK OF ENGLAND; TO THE GENERAL DISPENSARY, ALDERSGATE STREET; TO THE PROVIDENT CLERKS' MUTUAL BENEFIT ASSOCIATION, ETC. ETC.

SECOND EDITION.

REVISED, CORRECTED, CONSIDERABLY ENLARGED, ILLUSTRATED WITH ELECTROTYPES AND NUMEROUS WOODCUTS.

LONDON:

E. PALMER, 103, NEWGATE STREET;

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PATERNOSTER ROW.

1843.

TO

HIS ROYAL HIGHNESS

THE PRINCE ALBERT,

K.G., F.R.S.

SIR,

THE GRACIOUS PERMISSION TO RE-DEDICATE THIS VOLUME TO YOUR ROYAL HIGHNESS, HAS INDUCED ME TO STRIVE BY EVERY EFFORT TO RENDER THE NEW EDITION MORE WORTHY OF SUCH DISTINGUISHED PATRONAGE. FEELING, HOWEVER, MOST DEEPLY, THAT BUT A VERY PARTIAL SUCCESS HAS FOLLOWED MY LABOURS, I MUST CONTINUE TO RELY MORE UPON THE KIND CONSIDERATION OF YOUR ROYAL HIGHNESS THAN ON THE INTRINSIC MERITS OF THE WORK ITSELF.

I REMAIN,

WITH THE GREATEST RESPECT,

SIR,

YOUR ROYAL HIGHNESS'S MOST DUTIFUL

AND MOST OBEDIENT SERVANT,

ALFRED SMEE.

PREFACE.

I SHOULD not have presumed, in the first instance, to have composed the present volume, had I not been earnestly solicited to undertake that important office, especially as I foresaw the difficulties which would arise in such an attempt. A similar apprehension of inability thoroughly to investigate the subject has also deterred me, during the long time that this volume has been out of print, from re-writing it. At length, however, having determined to revise my previous labours, I commenced the task of writing the Second Edition with an unwillingness exceeded only by that with which I began the first. The cordial reception, however, of the former, made me the more anxious to render the present deserving that favour, which I am afraid was too liberally bestowed upon my first attempt.

In prosecuting my labours such extensive alterations, corrections, but more especially additions, have occurred, that this volume has rather become a new Treatise than a Second Edition. Notwithstanding that the work has been doubled in bulk, and partly re-written, it has afforded me great pleasure to discover that the new matter has arisen either from an addition or substitution of new inventions, or an extension of those before known, and not from errors in the former experiments. In fact, the more the subject is examined, the more fully do the principles regulating the

various branches of the science then developed appear to be confirmed.

It may not be too much to hope that the addition of the proximate and intimate rationale of the production, or rather the motion of electricity, may be useful beyond their immediate and important bearing on Electro-Metallurgical operations. The detail of the electro-chemical decomposition of a large number of metallic salts, together with the laws regulating the nature of the metallic deposit from simple and complex solutions, may also afford an instructive source of inquiry to all interested in the study of electricity.

It is almost needless to add, that what is novel in this work is given for public utility, and whatever has arisen from my experiments at any time has also been similarly thrown open. The former edition was issued to the public on the 26th December, 1840, and the present edition, although bearing the date of 1843, according to the custom of the trade, was published as follows: the first 40 pages on the 1st April, 1842; 40 pages more were ready on the 1st of May; the third 40 on the 1st of July; the succeeding 40 on the 1st of August; the fifth part, containing 44 pages, was published 1st September; the sixth part, to the 236th page, on the 1st of October; the next 40 pages on the 1st of November, and the remainder on the 1st of December.

Nothing is more difficult than to appreciate with accuracy the exact effect which the discoveries of each individual have on any particular science, and as far as regards electro-metallurgy, I feel utterly unable to undertake such a task. The principal names of those, however, whose various writings and inventions have been most useful to me in prosecuting my electro-metallurgical experiments, I have thought right to insert in the title page without reference to the relative benefit of their labours. If there is one philosopher to whom I am more indebted than another, I should without hesitation name Faraday, to whom my hearty thanks as the most enlightened

electrician that the world has ever produced are justly due. There may be many others at home and abroad, who doubtless have materially aided electro-metallurgy, besides those before-mentioned; but as they have had but little or no influence on my proceedings, it would be improper to place them in the title-page of my work.

Were I to call public attention to all who have directly or indirectly afforded me assistance in the collateral branches of electro-metallurgy, a list of names would surprise my readers, from its length; for I regret to state that I have been utterly unable to rely alone upon my own labours, and, therefore, have been compelled to cull information from the studios of artists, the galleries of sculptors, the laboratories of chemists, the workshops of artisans, and of various manufacturers, and frequently even from the books of merchants, and the productions of other electro-metallurgists. In a few words, arts, science, and commerce, have lent their aid to further the progress of electro-metallurgy, and I can call to mind no instance of a request to see any particular manufacture having been denied; but on the contrary, a free invitation to examine any subject that might help the application of electricity for the purposes of mankind.

As in the former edition I had to record my obligation to my friend, Mr. John Beadnell, for lessening the errors by correcting the proof sheets, so am I indebted, in a great part of this work, to my neighbour, Dr. Munk, for a similar exercise of kind offices. To my brother-in-law, Mr. Hutchison, my readers are again indebted for a most voluminous index.

The design of the medal in the title-page was kindly made for this work by the learned Mr. Thomson, of the London Institution. It affords me great pleasure to be enabled to draw the attention of my readers to its execution, for by a newly-invented machine 200 lines are ruled to the inch; and, therefore, if the lines forming the design were crossed, eight millions of spaces would be contained in a cubic inch. To

form any idea of the minuteness and beauty of the workmanship the use of a magnifying glass is required, and it will be found most amply to repay such an examination.

With all my assistance from others, superadded to the ardour with which the extraordinary character of the subject must necessarily inspire every person entering upon it, the variety of subjects comprised in the present work is so great, and so far removed from my daily professional avocations, that it will doubtless not appear strange for those who entirely devote their time to particular arts, to discover errors and imperfections. As these subjects, however, are only appendages, or extraneous matter, to electro-metallurgy, of which this work professes alone to treat, I trust the indulgence of the public will be extended to their criticism; but let the purely electro-metallurgical details be thoroughly examined, minutely sifted, and purged of their errors and imperfections, that at length truth may be exalted and electro-metallurgy triumph.

No. 7, Finsbury Circus, London,
Nov. 17th, 1842.

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HISTORY

OF

ELECTRO-METALLURGY.

We have not to extend our enquiry into remote periods, to trace the history of the arts of working in metals by the galvanic fluid, for truly it may be said that this art belongs to our own time, and is a characteristic of the present age. Whilst, however, we pursue our investigations into the history of this subject, we find that it has had by no means a sudden origin; for, at different periods, various persons have, by degrees, worked out one fact after another, till the comprehensive science has been developed, of which this volume is but a brief epitome. Electro-metallurgy may be said to have had its origin in the discovery of the constant battery by Professor Daniell, for in that instrument the copper is continually reduced upon the negative plate. In his first experiment, this distinguished author observed, on removing a piece of the reduced copper from a platina electrode, that scratches on the latter were copied with accuracy on the copper. In this experiment we have the electrotype; but the author, in the first paper detailing his experiments, had devoted all his attention and centred all his energies to the construction of the battery itself, and this valuable fact attracted but little of his notice.

It was but a short time after the discovery of this battery, that Mr. De la Rue experimented on its properties. In a paper printed in the Philosophical Magazine for 1836, after describing a peculiar form of battery which he adopts, the

following remarkable passage is found: "The copper plate is also covered with a coating of metallic copper, which is continually being deposited; and so perfect is the sheet of copper thus formed, that, being stripped off, it has the counterpart of every scratch of the plate on which it is deposited." This paper seems to have attracted very little attention; and, what seems still more singular, the author, although well qualified, from his scientific attainments, to have applied these facts, never thought of any practical benefit to which this experiment might lead.

In this state the subject remained till October, 1838, when Professor Jacobi first announced that he could employ the reduction of copper, by galvanic agency, for the purposes of the arts. His process was called galvano-plastic. Immediately upon his discovery being announced in this country in 1839, Mr. Spencer stated that he had executed some medals in copper, to which the public afterwards gave the name of electrotypes or voltatypes, or, what is better, electro-medallions.

Now what is the precise value of the discovery of these productions over the facts already described?—for we have seen that the reduction of the copper as a perfect plate, taking the exact form of the negative metal on which it was deposited, had been already noticed. Why, it is simply the idea of the application of these facts; but that idea has been everything for Electro-metallurgy. The only apparatus which Mr. Spencer employed was, in fact, a simple Daniell's battery. He employed various metals for the reception of the precipitated metal, which, however, was nothing new; but he does not seem to have succeeded with any non-conducting substances. He executed medals, and perhaps duplicate copper plates; but he does not give any details, as to the different methods for the reduction of the copper in different states, neither did he succeed with the reduction of any other metal. However, to Mr. Spencer the British public are principally indebted for the idea of the electrotype; and perhaps the idea;

as far as relates to its application in Great Britain, originated entirely with himself.

Mr. Spencer's first paper was printed in the journal of the Polytechnic Institution of Liverpool, in 1839; but the author complains, that by mismanagement it was prevented from being read at the British Association. Any discouragement of science in the present time is greatly to be lamented, and the more especially when we see that the Germans are already taking the lead, not only in chemistry, but also in physiology. Every well-wisher of science must hope that an over anxiety to prevent the publication of what is old, will not cause the referees of our learned societies to omit what is new. However, we are not so much behind-hand, but that a little zeal on the part of those who have an established reputation for scientific acquirements, joined to the effect which encouragement would have on the junior members of the country, will enable the British to keep the foremost rank in science among the European nations. There are many now working zealously and ardently for the sake of obtaining truth, struggling against the most disheartening opposition: let that opposition be changed to assistance, and great indeed will be the results.

It is improper to throw the whole blame of the rejection of that paper upon Dr. Lardner, for this is by no means the only essay of importance which has been consigned to oblivion. The rejection of valuable papers is a fault of the system not of the man. At all the learned societies a paper submitted to the society is referred to persons to report upon its merits, and upon that report the committees act with regard to its publication or suppression, which, in some cases, is facetiously termed a careful deposition in the archives of the Society, which expression literally means, that it is placed in some large box from which it will be excluded from the cheering influence of the sun's rays for ever. The examination into the merits of any particular paper is, however, a most unthank-

ful, disagreeable, and troublesome office. And it is not, therefore, surprising that the referees should sometimes exercise their characters as men, in supporting their own or the opinions of their friends and those to whom they are under obligations, and occasionally forget their situation as judges. Their services being gratuitous, entitle the referees to the heartiest thanks of the public; but an important office like that they occupy, in which the prosperity of the whole country is interested, should decidedly not be held without remuneration, and when remunerated the officers should be held responsible for their decisions. We perceive that had Jacobi not also been a discoverer of the electrotype, electro-metallurgy would not have added its valuable processes to the variety of arts which it comprises. Ponder this important matter ye referees! carefully in your minds, for you never can tell to what great end a single new fact or application, though in an ill-drawn up paper, may not ultimately tend.

Perhaps in this place I may call the attention of scientific men to the fact, that persons are actually employed by great Continental Powers to find out everything new that is discovered in this country, which, in a very few hours, can be conveyed to any part of Europe. This hint is thrown out, not to deter Englishmen from generously giving their discoveries to all countries, but to cause them to be cautious not to mention their processes till they have appeared in some British publication, and thus vindicate the scientific character of our own country. This is the more necessary, as the English receive only the pleasure which the consciousness of being useful must afford, whilst the foreigner receives pecuniary emolument which singularly increases his desire of being acquainted with the inventions of other countries.

I may further notice, in order to confirm what I have already stated, that the galvano-plastics of Jacobi, and the electrotype of Spencer, are not inventions the result of inductive reasoning and laborious research, like Professor Wheat-

stone's electro-telegraph or certain elaborate machines; but merely an application of a fact, formerly known to Daniell, recorded particularly by De la Rue, and observed by hundreds of others, that both Spencer and Jacobi could work only in copper, and in no other metal; whilst, had they prosecuted their subject as a science, they would have seen that the same laws regulate the reduction of all the metals.

Electro-metallurgy as first made known to the world by Jacobi and Spencer was the simplest of all inventions — the application of a fact known and recorded previously; and it forms another instance of an invention of the greatest magnitude and utility to mankind, arising from most simple beginnings.

The next discovery, which is fully equal in value to the idea of the electrotype itself, was made by Mr. Murray. He found out that non-conducting substances might have metallic copper thrown down upon them by previously applying black lead. Mr. Murray's process is extremely simple, and absolutely perfect. The first application of this invention was made in January, 1840; but it is to be lamented that he did not further extend its application and publish his researches, for his method was communicated orally, in the conversaziones of the Royal Institution, and not by any paper. I lay particular stress upon the value and perfection of plumbago, because some have denied its applicability; and the reader will find, throughout the whole of the work, that I have extended the use of this substance, to the benefit of the public and to the fame of the inventor. I have made very extensive enquiries, in order to ascertain who really first used plumbago for this purpose, and I have the testimony of several authorities that it was Mr. Murray, whose claim, therefore, to this invention is rendered quite indisputable.

Since the above was written, I am happy to inform my readers that the Society of Arts thought fit to record their sense of the value of plumbago to electro-metallurgy by presenting

Mr. Murray with a silver medal; and perhaps the merit of Mr. Murray's discovery is much enhanced by black lead not only answering its purpose most fully, but from being so simple that very few were likely to have thought of its application. I cannot conceive a more perfect substance than black lead for this purpose, for the adhesion of hydrogen to it is so great that it would rather reduce a metallic salt than be evolved; and this is the very property desirable for electro-metallurgy, and in this respect forms a striking contrast with the processes subsequently given by Mr. Solly and Mr. Spencer, though, doubtless, had we not Mr. Murray's process, they would have formed valuable additions to electro-metallurgy.

Up to April, 1840, the single-cell apparatus was invariably used, but then Mr. Mason very ingeniously devised another mode by which the reduction might be effected. He used the single-cell apparatus as a Daniell's battery, which he connected with another cell to reduce another metal. In the second cell he used a copper positive electrode, which was dissolved during the action. By this means he made two metals by one pound of zinc, or, in other words, obtained two equivalents of copper for one of zinc.

In the London Journal for April, 1840, as far as I know, is contained the first specimen of printing from an Electrotype, by Newton. It is a small, rough sketch, but as the first of the kind is peculiarly interesting.

The laws regulating the reduction of all metals in different states were first given in this work, as the result of my own discoveries. By these we can throw down gold, silver, platinum, palladium, copper, iron, and almost all other metals in three states, namely, as a black powder, as a crystalline deposit, or as a flexible plate. These laws appear to me at once to raise the isolated facts known as the electrotype into a science, and to add electro-metallurgy as an auxiliary to the noble arts of this country.

The regulation of the power of the battery to the strength of the metallic solution, also required an investigation of the principles which regulated the diffusion of the newly-formed salt, which is of great importance to the operator. In this work I have also appended data whereby the manufacturer may calculate the expense of particular processes before he adopts them. The formulæ for ascertaining the work that would be performed by a galvanic battery, under different circumstances, cannot fail to be of great utility to the workman, if he rightly employ them; and the intimate rationale of the motion of electricity in the battery must be a subject, at least, of great interest to all. The principle regulating the adhesion of the reduced metal is also one of paramount importance in all cases where it has to be removed from the plates on which it is deposited.

The number of experiments, I may even say the thousands, that have been tried to elucidate these laws, (for this book is not a detail of experiments, but rather a digest of them,) could never have been executed had I not first discovered my galvanic battery; for its simplicity alone enabled me, without any assistance, to undergo the laborious undertaking. I am fully aware that some may disagree with me as to the superiority of my battery over all others for experimental and manufacturing purposes. I shall not flinch upon this account from stating its advantages, especially as they appear to me likely to contribute to general benefit.

The value of the battery process over all others, is its applicability to all cases; moreover, when we use a single cell of the battery, the quantity of zinc dissolved to do any amount of work, is the same, or even less, than attends the use of the other apparatus; because the local action in a battery of this construction is less than in the single-cell apparatus; and, lastly, the quality of the precipitated metal can be regulated with the utmost nicety; and I have no

hesitation in stating, that the battery process is the only one that ever can be employed by the manufacturer with advantage.

The platinized silver battery is peculiarly suitable for the operator, for when it is in action it communicates to him the degree of work that it is doing; in fact, it completely talks to its possessor. If the current is very feeble, a faint murmur is heard; if a little stronger, the battery whispers; if a moderate current is passing, it hisses; but if a violent one, it roars. At this present moment I have nineteen batteries at work in the same room where I am writing, and they are each telling me the work they are performing. This very instant the fall of a heavy ledger in a neighbouring office has jarred two wires into contact, and the roar of that one battery has immediately informed me of the fact, notwithstanding the action of the eighteen others; I have separated the wires, and the universal singing communicates to me that all are now working satisfactorily. Any local action on the zinc in the same way is immediately notified by its different and peculiar voice, and I have been surprised how quickly the experimentor catches the characteristic peculiarity of each noise, which is learnt more readily than the sound of different bells in a strange house.

With regard to the constancy of this battery, I may be expected to say a few words, for, although theoretically it is not absolutely constant, yet practically, for the purposes of the electro-metallurgist, its constancy remains for two or three days, or, in other words, until the battery is nearly exhausted; and then, to replenish the solution of zinc with a fresh supply of dilute acid will not occupy more than half a minute. In recording my own experience of its practical, though not of its absolute constancy, I can at the same time conjoin the testimony of some of the most extensive manufac-

turers in this country. By the practical manufacturer this instrument is re-charged with acid, at intervals, varying from three days to a fortnight, according to the size of the vessel containing the acid. Whilst upon the use of the battery, I may state, that the platinum, with proper care, never wears off the silver, and that the platinized silver never undergoes the slightest change, or is affected by the slightest local action.

The departments of electro-metallurgy comprising electro-gilding and plating, received great impulses from Elkington; some of his processes being most admirable. As far as gilding is concerned, he was anticipated by Brugnatelli nearly forty years ago; the following passage has been pointed out to me by Mr. Brayley, the sub-editor to the Phil. Mag. "I have lately," adds he, (Brugnatelli, in a letter to Van Mons,) "gilt in a complete manner two large silver medals, by bringing them into communication, by means of a steel wire, with the negative pole of a voltaic pile, and keeping them one after the other immersed in ammoniuret of gold newly made and well saturated." This account is contained in the Phil. Mag. for 1805, but the same passage is also found in the "Archives of Philosophical Knowledge;" but it is to be regretted that neither journal gave the letter or stated where it was published. This process differs in nothing from the ones now employed, and doubtless ought to be considered as the introduction of electro-metallurgy, being the first instance in which any metal was ever reduced by galvanism for the purposes of the arts.

The processes for platinating, palladiating, &c., rest upon the authority of this work; for hitherto the reduction of these metals, in any other state than that of the black powder, has been always considered impossible. The electro-metallurgist will be enabled, by the processes which he will find here fully described, to execute reliefs and intaglios in gold, and, in fact, in nearly every other metal; facts altogether new in science.

The working of all other metals, as in zinc, silver, &c. &c., except copper, is also due to the discovery of the laws regulating the precipitation of the metals.

Every author has given directions for making moulds on plaster casts in metal; but it is singular, that by no process hitherto known can a perfect reverse of plaster be obtained. In investigating the cause of this, I soon discovered that the extreme porosity of the plaster was the block over which they had all stumbled, and the difficulty was overcome by rendering the plaster non-absorbent. In this work the reader will find that the copying of reliefs in plaster is brought to the utmost possible perfection, and by very simple means.

The success of this department of my experiments has amply repaid me for my labours and expense; for there is not a town in England that I have happened to visit, and scarcely a street of this metropolis, where prepared plasters are not exposed to view for the purpose of alluring persons to follow the delightful recreation afforded by the practice of electro-metallurgy.

The extended use of white-wax, bees'-wax, rosin, &c., for the electro-metallurgist, I trust will be found acceptable. Their manipulation I have given as the result of my own experience, and therefore, doubtless, those who make a trade of working these substances will find the account not so full as might have been expected or wished; yet I believe practice alone is required to make the operator perfect in these arts.

The application of electro-metallurgy to the copying of leaves, fruit, &c., is for the first time described in this work. The new mode of etching here detailed, I confidently trust, will be also found a valuable adjunct to the knowledge of the engraver. The principle which regulates the adhesion and non-adhesion of the plates will enable the operator to conduct his operations with certainty—a circumstance of no small

importance to the engraver, ignorance on this score having already produced untoward results.

In this history, a sketch only has been given of the leading discoveries ; but undoubtedly the person who carries out a new science is deserving of considerable praise, for frequently he has to incur great expense without any immediate prospect of a return for his capital.

The Electrotype department of Electro-Metallurgy was, I believe, first undertaken as a business by Mr. Palmer; who was speedily followed by De la Rue, and afterwards by Lockett, Mabley, and several others: though, not having seen the productions of the latter, I have been unable to report more minutely of their works.

The laws which I have given in this work, and the universality of their application, will doubtless influence importantly the attainment of the grand object of using the galvanic fluid commonly among our manufacturers; and having thus, as I believe, raised the isolated facts called the Electrotype into a vast and comprehensive science, a new name is required which may be suitable to its importance, and embrace its various applications. The term which I have ventured to apply to the science is ELECTRO-METALLURGY, which comprises the principles regulating all the arts of WORKING IN METALS BY THE GALVANIC FORCE; and the value of the new nomenclature is evident, when we consider that it takes in every mode by which it is possible to work metals, either by dissolving or precipitating them, by the agency of the voltaic current.

As a surgeon, I feel bound to pass my opinion upon the effect which an extensive application of electro-metallurgy would have on the health of the workman; and in one word I may state, that I believe the mode of working in metals by the galvanic fluid is more wholesome, and attended with far less deleterious properties, than the methods now practised. The use of the salts of gold, silver, and platinum, is

liable to discolour the fingers; but the other salts have no particular effect. However, in passing the above decided opinion, strengthened as it is by watching the effects of the experiments on myself, and also from paying attention to the health of some who have reduced electrotype copper by the hundred-weight, I feel but little doubt, that, if the electro-metallurgist were several times in a day to leave his work with his fingers covered with metallic solutions, and take his meals without any ablution, and repeat this for a long time, the quantity of metal which he would thus draw insensibly into his system might be attended with inconvenience. Several of the processes here detailed, as those of gilding, &c., are likely most materially to benefit the health of the workman, as they supersede the use of pernicious mercurial fumes.

Those conducting electro-metallurgical operations generally fatten with their occupation, the minute quantities of sulphate of zinc and sulphuric acid which they imbibe improving the tone of their stomach, helping digestion, and strengthening the whole frame. The salts of copper have the same effects as those of zinc, but perhaps, upon the whole, must not be made quite so free with. I would warn my reader against too free and careless a use of the cyanides, believing that the simple inhalation of the vapour which they emit is very pernicious; but with proper care no fear need be entertained, and, doubtless, upon the whole, electro-metallurgy is a great blessing to the workman.

The Electro-Metallurgist who requires further information on galvanism, should consult the original papers of the various authors who have most contributed to a knowledge of the subject; but I would especially urge every person interested in any department of Electro-Metallurgy to buy and keep ready for reference Brande's Manual of Chemistry, the most extensive and general collection of chemical facts in the English language. The operator will find it indispensable if he attempt to leave the beaten track and follow new paths.

No person can now plead ignorance of Electro-Metallurgy as an excuse for not following it. There are such a variety of works upon the subject to suit every class of persons, from a penny up to three or four shillings, that certainly he must be enabled to purchase one according to his means. The best of them are generally written by workmen, who detail, in their own language, the processes they are in the habit of using. Those works that are made up by abstracting a part from one author and part from another, generally lose force from the inconsistent whole that they present; though, doubtless, there is not a single treatise upon the subject that might not be useful to the incipient operator, and from which some good might not be drawn.

It has often been mentioned to me, and considered strange, that the Societies whose business it is to superintend and cherish the rising arts and infant sciences, should not contain any single paper on the new science of electro-metallurgy, and that the student is compelled to obtain his knowledge from other sources. For the electrotype, he may possess Spencer's treatise on that subject, although the mode of proceeding detailed by him is very different from those which the laws I have developed require me to recommend. Jacobi has written a treatise, in German, on Galvano-plastics, which has been translated by Sturgeon. These two books, from respect to their authors, every electro-metallurgist should not only possess, but value and carefully preserve, as the first dawn of this delightful science. The manufacturer would do well to consult the various electro-metallurgic patents, the titles of which are given in the Appendix of this work, and an abstract of many of which are printed in various magazines. The original papers upon electro-metallurgy have now become so numerous, that every periodical contains notices, of various degrees of value and novelty, in some portion of this extensive subject. The value of these excellent periodicals in making public new

discoveries and fostering talent, which would otherwise be frequently crushed by the overwhelming weight of interested opinion, is here evident, and to their spirited editors this country is daily owing increase of knowledge, power, and wealth.

ELEMENTS

OF

ELECTRO-METALLURGY.

BOOK THE FIRST.

ON GALVANISM.

CHAPTER I.

ON GALVANIC BATTERIES.

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(1.) As chemists have arranged an extensive series of effects under the general term of Heat, so they have named another series Light, and a third they have called Electricity. Of the first cause of all these, as of that of vitality, we are ignorant, for we can only examine them by their effects, and even their nature is equally obscure. We find, if we examine organized bodies, that all these principles are capable of being produced through the medium of life, for nearly all animals have the power of evolving heat; many insects, moreover, can voluntarily emit light; and the property of producing electricity is well evinced in the terrible shock of the electric eel, as well as in that of some other creatures. We are indeed in the

habit of talking of the Electric fluid, or the Galvanic fluid, but this in reality is nothing but a licence of expression suitable to our finite and material notions.

(2.) Their weight is inappreciable by the most delicate balances, and hence they have been termed the imponderable agents; a property in which they all agree, and in numerous cases appear to be singularly and intimately connected with each other.

(3.) Electricity is the only one which we have particularly to treat of in this work, and this subject is subdivided into several departments: as, electricity of tension, or frictional electricity, where the effects of electricity derived from the electrifying machine are considered; thermo- or steræo-electricity, where it is derived from solid bodies through the agency of heat; animal electricity, from organized bodies; magnetic electricity, from the natural or artificial magnet; and voltaic or galvanic, where it is obtained from the voltaic pile.

(4.) Although these names, from their multiplicity, may tend to confuse, be it remembered, there is but one electricity which thus manifests itself in such different ways, either under varying circumstances, or from differences from whence it is derived. Our enquiry will not extend into all these details, but simply into its effects when obtained from the voltaic battery.

(5.) The phenomena, to which the name of voltaic or galvanic electricity has been given, are those which arise from the voltaic or galvanic battery, so named from its discoverers, Volta and Galvani. They found that two pieces of metal, possessing different facilities for combination with oxygen, produced, when properly united, singular convulsions in a dead frog; and, following out this experiment, they constructed the battery, which has now, from the improvements of later discoverers, become so powerful and valuable an instrument.

(6.) Without pursuing in detail the interesting experiments

of subsequent authors, it must always be borne in mind, that, to make a galvanic battery with advantage, two conducting substances must be employed, and a compound conducting fluid must intervene, capable of being decomposed, and the resulting compound formed should be removed as rapidly as possible out of the sphere of its production by the solvent powers of the fluid. The first substance should have the strongest possible affinity for one element of the fluid, and the second substance the least possible affinity. Thus, in a simple circuit, composed of zinc, silver, and water, (the water being rendered a good conductor by the addition of acid,) zinc has a very strong attraction for the oxygen of the fluid, whilst silver has a very slight attraction; and therefore a powerful current is generated. As a galvanic curiosity Becquerel has described a battery made by an acid and alkali, separated from each other by a porous diaphragm, and simply connected by a platinum wire. Mr. Grove has also described an interesting arrangement of nitric acid and muriatic acid, separated by a diaphragm and connected together by gold leaf immersed in both fluids. In this case oxygen is transferred over to the muriatic acid, chlorine is set free, and one piece of gold becomes dissolved. The older electricians considered that galvanic batteries might be made of muscle and brain, beet-root, and various other non-conducting substances, but probably their observations are inaccurate.

(7.) With regard to the relative conducting powers of bodies, the metals, and all the varieties of carbon excepting the diamond, hold the foremost rank among solids. The fluids are generally imperfect conductors; none more so than pure water; though in combination with the acids, pure alkalies, or any of the salts, it forms a good conductor. Fused chlorides and iodides are also good conductors. The metals are conductors in the following order; silver, copper, lead, gold, brass, zinc, tin, platinum, palladium, and iron.

(8.) If we except the earthy and alkaline metals, as potas-

sium, sodium, &c., zinc has by far the strongest affinity for oxygen; and on this account is invariably used as the electro-positive metal (the term applied to the metal which is acted upon by the solution, or which in reality acts on the fluid). All other metals, in any *acid* solution, are electro-negative to them; the term used to imply the opposite state to electro-positive. The following table shows the state of electricity in which the metals stand with regard to each other in acid solutions, where every metal is positive to all below it, and negative to all above it. This series relates only to a dilute sulphuric acid solution, for it varies with almost every other solution used:

Potassium,	Iron,	Silver,
Barium,	Bismuth,	Palladium,
Zinc,	Antimony,	Gold,
Cadmium,	Lead,	Charcoal,
Tin,	Copper,	Platinum.

This order appears to me to require to be again made the subject of experiment; I would suggest that, for this investigation, every metal should be used in a finely divided state, similar to the finely divided platinum of my battery.

(9.) When a metal which acts slightly upon a fluid (as for instance, copper) is brought into contact with another metal, which has a stronger affinity for the oxygen of the fluid, the latter, or electro-positive, is dissolved, and gives a negative tendency to the former, which in that state does not act at all upon the fluid, but is preserved by the latter. Of this singular property Sir H. Davy took advantage, for the protection of the copper sheathing of vessels, which was effectually preserved from decay by pieces of zinc or iron placed in contact with it under the water; but then unfortunately the copper, ceasing to be deleterious, did not prevent the adhesion of marine animals and vegetables, which accumulated to such an extent as materially to impede the ships' progress through the water. In this way zinc protects all the less oxidable

metals, when pure; but if the electro-negative metals be contaminated with charcoal, or with a metal having less affinity for oxygen, they will still be acted upon. This doctrine of negative tendencies appears to be much overrated, for a metal can only be protected by the negative tendency, when hydrogen has to be evolved from the metal to be protected; thus, zinc will protect copper when placed in dilute sulphuric or other saline solutions, but no voltaic force will protect the copper when placed in the salts of silver, gold, platinum, or palladium, or in nitrous acid, because the hydrogen in these cases is immediately absorbed, and the copper is acted upon by the liquid, or rather itself decomposes the fluid, by seizing upon the oxygen of the metallic salt. For the same reasons it is impossible to give a negative tendency to iron or tin, in a solution of sulphate of copper, because there is no hydrogen to protect the iron. There are a thousand other similar instances; therefore let the electro-metallurgist place no reliance on giving a negative tendency to a metal, but take care in all his operations not to place one metal in a metallic solution which it is enabled to decompose.

(10.) The converse of this observation applies to the electro-positive metal, as the zinc; for, when pure, it is not acted upon by the sulphuric acid till contact be made with some other metal having less affinity for oxygen: if it contain any electro-negative metal, however, it will not only be acted upon by the fluid for the generation of the galvanic current, but independently of this a great waste and expense will be incurred. This additional wasting is termed local action, and should be avoided in every possible way.

(11.) Local action, arising as it does from either the zinc or the negative metal being contaminated with some other metal, is to be considered as an infinity of small batteries, the action of which is quite independent of the great battery; where the hydrogen is entirely transferred to the negative plate, and where consequently no apparent action is visible at the positive plate.

(12.) It is for this reason that the pure metals are exceedingly difficult to dissolve, particularly if the acids be also pure; as, for instance, pure silver in pure diluted nitric acid, or pure zinc in dilute sulphuric acid; because there is no local battery of different metals established to favour the solution.

(13.) A battery, in an acid solution, when put into action, exhibits apparently no change at the electro-positive metal, or zinc, if the local action be destroyed; although in fact it is the zinc which is being dissolved. On the contrary, the electro-negative metal, which is in reality undergoing no change, exhibits a copious disengagement of gas, which arises from the transference of the hydrogen to that plate, while the oxygen is all absorbed by the zinc.

(14.) This leads us at once to the proximate cause of the voltaic current, for it is found that the amount of action on the zinc is exactly proportionate to the quantity of electricity produced; hence zinc appears to be the fuel of the battery, holding the same place as coals in a fire. From these and various other facts, Dr. Wollaston, Dr. Faraday, and with them most of the present experimenters in this country, believe that the chemical action of the acid solution on the zinc, or rather of the zinc on the water of the acid solution, is the source of the electric current in the voltaic battery; and this is termed the Chemical Theory of the pile. The Germans again, and others, following Volta, believe that the chemical action is the effect of the electric current, and that the power is produced by the contact of two dissimilar metals; and this latter has received the name of the Contact Theory.

(15.) In opposition to the Contact Theory, Dr. Faraday has described, in the Philosophical Transactions, curious instances, where the connection of a single battery, excited by dilute sulphuric acid, was not made through any metal whatever, but through a liquid capable of being decomposed by the stronger energies of the dilute sulphuric acid. He found that a solu-

tion of iodide of potassium was best adapted to show this interesting fact.

(16.) Whichever theory be adopted, the use of the negative metal is by no means apparent; for the quantity of electricity developed, cæteris paribus, is exactly as the surface of negative metal exposed: thus, provided there be no obstacle to overcome, if the surface of this be doubled, the quantity of electricity will be likewise doubled. The extent of surface of the positive metal, within certain limits, is not of so much consequence, although too great a deficiency of this is attended with detriment. The importance of the surface of positive metal differs with every metal, and perhaps depends more on the attributes of the salt formed during the action of the battery. In a dilute acid solution, when zinc is used for the positive metal, the extent of surface is not very material; but when other metals, as copper or iron, are employed in a decomposition apparatus, the size is of the utmost consequence, as we shall hereafter have particularly to notice.

(17.) One circumstance must be noticed, that every point of the negative offers a radiating point to the positive metal; for every point not so situated is much less active, and sometimes even perfectly inactive. In different cases this property is shown more or less strikingly; for if the hydrogen be removed in its nascent state, it will, under the combined action of its adhesion and elasticity, manifest itself at a great distance from the positive metal, and even quite without the sphere of its radiation, as is the case where the back of a piece of metal is active, while the front alone is opposite to the fluid. When very smooth metals are used, it will also pass to a great distance; but when a metal is prepared in the manner I have hereafter to point out, by platinum, the gas will only be given off from a small extent, though very violently, when touched by the point of a fine zinc wire. In fact, the stratum of fluid interposed between the pieces of metals affords a great resistance to the galvanic fluid, and this

proportionate to the thickness of the stratum and its conducting power.

(18.) A relation exists between the power, and the distance interposed between the electro-positive and negative metals; for, the nearer these can be brought together, the greater the quantity of electricity developed; though the intensity is not influenced by the difference of arrangement.

(19.) The function of the acid solution has already been partially explained; for we have before mentioned that the water is decomposed, the hydrogen is transferred to the negative metal, and the oxygen combines with the zinc, and forms oxide of zinc. The acid now comes into play, and, in addition to its adding considerable conducting power to the solution, it removes the oxide to form the sulphate of zinc. The water which now remains undecomposed is required to dissolve the sulphate of zinc, for, as soon as the liquid becomes saturated with that salt, no farther galvanic action can take place, although the liquid may still remain intensely sour. This property is of great importance, because it shows us that the acid and water must be so regulated that the sulphate of zinc which results from the action may saturate the water and leave little or no excess of acid. Whatever acid is left beyond the saturation of the fluid by the sulphate of zinc must of necessity be wasted, unless we dilute the solution with more water. It is a most striking experiment to add water to a battery charged with a saturated and acid solution of sulphate of zinc, as immediately activity and power are exhibited by that which appeared before to be inert and inoperative. The function of the water has been very much overlooked, or even altogether neglected; but for electro-metallurgical operations the fact must be continually borne in mind, and a sufficiency of fluid always added to the metallic salt, in order that when the salt is formed it may be freely dissolved. If the rivers had been filled with anhydrous sulphuric acid, and water had been manufactured in the laboratory, then we should have come to

the conclusion that the water excited the battery, and the acid was of secondary importance; but, as it has been the reverse, we have decided too carelessly that the acid excited the battery, and the water played a secondary part; whereas the one is as necessary as the other, the acid to render soluble the metal, the water to dissolve the newly formed metallic salt. Different salts vary very much in the rapidity with which they are dissolved by fluids; thus sulphate of zinc is very rapidly dissolved, ferrocyanate of potash and sulphate of copper very slowly, and this does not depend upon the quantity of salt the water will take up; and there is no doubt that this property is of considerable importance, not only in the galvanic battery, but also in the precipitating trough. After these observations, we must not be deceived by imagining we can have a battery which will do much work, and at the same time take up but little space; for any person may at once calculate the capabilities of a battery from its size, by first ascertaining the nature of the salt formed by the galvanic action, then its solubility in water, by which means we can learn to a nicety the utmost amount of galvanic power that can be attained from any battery. The only chance we have of lessening the size of a galvanic battery, and at the same time performing the same work, is to take care that the salt made during the action of the battery should be soluble in but little water.

(20.) Whatever exciting fluid is employed to charge the battery, its efficacy depends upon the same principles, but the intensity varies with each variation in the foreign body placed in the water; thus dilute nitric acid, dilute sulphuric acid, or a solution of salt, all impart different powers to the battery: an increase, however, or diminution in the proportion of these, does not interfere in the intensity, though the quantity is materially altered; for, if but ten drops of dilute sulphuric acid are placed in a gallon of water, the intensity would be the same as if a pint of acid were employed; but

the quantity in one case would be infinitely less than in the other.

(21.) The nature of the exciting fluid also materially affects the resistance which is afforded to the galvanic current, for no two fluids, or no two strengths of fluids, conduct the galvanic power with equal facility. From the above considerations we arrive at the proper manner to make a galvanic battery; first, we must have two good conducting substances, separated by a good conducting intervening liquid. The amount of action which it will produce will be proportionate to the ready action of the liquid on one substance, and its inaction on the other; and will depend on the size of the terminal plates. This amount of action may be fairly called the power of the battery, but it is always lessened; first, by a slight resistance which the metals afford to the passage of the current; and, secondly, by the resistance which the intervening liquid is sure to afford, which is proportionate to its thickness. If, instead of a good conducting metal, the connection between the terminal plates is made by any imperfectly conducting substance, then will also the power be still further immensely lessened. A single cell, composed of two metals and an intervening fluid, provided it be large, is sufficient to produce any amount of action where no resistance is afforded to the passage of the voltaic current. These will remain inactive while they do not touch; but as soon as contact takes place, either in the exciting fluid, at a distance, or through a fluid of more easy decomposition than the exciting fluid of the battery, the action immediately commences. The contact may be made through a great length of wire, with the same result. In this case, however, if the wire be either long, of small diameter, or of a metal of no great conducting power, it will be seen that the hydrogen evolved from the negative metal will be materially lessened, showing that an obstacle is presented to the electric fluid.

(22.) To overcome this obstacle we must have recourse to a

number of galvanic batteries, arranged as a series; that is, the zinc of one battery connected with the silver of the next, and this in regular continuation, leaving the extreme zinc and silver-free. In this way a hundred batteries may be conjoined, but no more electricity obtained; for only the same amount of electricity passes as when one cell is used. Now, however, this same amount can pass through a much greater resistance, for it would seem as if, at every alternation of the battery, the electric fluid obtained a push to overcome any obstacle afforded to its passage. The amount of electricity will have a power of overcoming obstacles in a compound battery, equal to its power in a single cell, multiplied by the number of cells. By this arrangement the amount of electricity actually passing will not be increased beyond what it would have been, had there been no resistance to overcome.

Ohm, in an elaborate and obscurely worded paper, has given the mathematical formula for the galvanic current. His general formula may be thus expressed. The intensity of action (A) is equal to (the electromotive force (E) multiplied by the number of batteries) (n) divided (by the resistance the current has to overcome, external to the liquid of each battery (r) plus (the resistance encountered by the peculiar arrangement of each cell r' multiplied by the number of cells (n))).

It would be thus:—

$$A = \frac{n\,E}{r + n\,r'}$$

The value of this formula would have been appreciated long since, had he not discarded the terms quantity and intensity, but modeled them to suit his new views. Had he restricted the term quantity to the amount of electricity passing at each point, and intensity to the power which that had of overcoming obstacles, in which sense I shall use these terms throughout this work, then would his doctrines have immediately had their due weight amongst scientific men, in-

stead of requiring years slowly but surely to work their way. To mathematicians this formula explains every circumstance observable in the use of galvanic batteries. It shows that the force of the single battery should be as much as possible, by using metals of different affinity for oxygen; then that the resistance in this single circuit should be reduced to the minimum, by using thick plates of metal, and a narrow interval of the best conducting fluid. Now if sufficient series be used, the greatest resistance can be perfectly overcome. It is instructive to substitute numbers for the letters of the formula, which will show all the capabilities and attributes of the galvanic battery better than any other way.

(23.) There is no advantage, but even a loss, in using a battery with a series more than sufficient to nearly overcome a resistance, whether produced by a fluid to be decomposed, or by any other means; for if ten cells arranged as a compound battery be sufficient to overcome the obstacle, the effect of sixty cells, arranged as six tens, would be nearly six times as much as if a single ten were used, because they would then form a battery of six times the size: but if the whole were used as one compound series, the resulting decomposition would be enormously less than six times the quantity, being but a trifle more than before; and, to use a battery with advantage, this fact must be borne in mind. If, again, the surfaces be increased before sufficient series be obtained, in like manner it will not add a proportionate amount of power.

(24.) A compound galvanic battery, or one of many cells, has the same quantity of electricity passing in each cell, and therefore the same quantity of zinc dissolved. On this account the fewer the cells that can be employed to overcome the obstacle, the greater will be the economy. It is obvious, therefore, that as soon as, by increasing the series, sufficient intensity has been attained to overcome partially the resistance, quantity should be sought by increasing the surface; for

when one cell, as a single series, requires one pound of zinc to do a given amount of work, when that same work is done more quickly by twelve cells, twelve pounds are dissolved—one pound in each cell; and of whatever size the cells may be, still the result will be the same, for no more zinc will be dissolved.

(25.) The simplest form of compound battery is the Couronne des Tasses, which is composed of alternate slips of zinc and platinum soldered together; the zinc is to be placed in one glass, the platinum in the next; and the series, thus arranged, may be charged with dilute sulphuric acid: care must be taken that the metal of the alternate pairs do not touch in the fluid.

(26.) When intensity alone is required, a large number of small plates should be used, as in De Luc's column, which is constructed of pairs of plates of dissimilar metals, separated by paper. There are several methods by which it may be made; the most common of which is to place alternate discs of silvered paper on similar discs of zinc, taking care that the series (i. e. the relative position of zinc) has always the same direction. It may be also made of discs of silvered or gilt paper, the uncovered side having been first spread over with the black oxide of manganese and honey. However, care must be taken that the manganese be not exposed to the sun, as in that case it is rendered inert; and also that the silver or gilt paper be not covered with any varnish, as that which is usually sold in the shops: 500 to 1000 discs must be employed to make an efficient instrument.

(27.) The larger batteries, which were in use for a number of years, consisted generally of copper and zinc, arranged in different forms, according to the fancy of the operator. Thus, the copper of each cell surrounded the zinc, and both were united to fit into a porcelain trough, with eight, ten, or more cells. Here each cell is to be considered as a distinct battery, although the copper and zinc of the whole trough are united;

an arrangement contrived to remove the series of batteries from the trough at one time.

(28.) In this compound battery a porcelain diaphragm separates each simple battery; but Dr. Hare discovered that a series of batteries might be placed in one vessel, provided that the metals of each battery did not touch in the fluid, and that neither the electro-positive metal afforded a radiatory point to the electro-negative metal of any other but its own pair, nor that any electro-negative metal radiated in a similar manner to any electro-positive metal. This form of battery is very little known in this country, and I believe but seldom used anywhere.

(29.) There is another form which was devised by Cruikshank, and which consists merely of square pieces of zinc and copper, soldered together, and fixed at regular intervals in a wooden trough; the zinc always being in one direction. In this battery the metals themselves divide the cells.

(30.) There are many other forms of compound batteries, which do not require particular mention, as the principles which have been already explained affect them all.

(31.) Provided the metals be sufficient to carry the current, their thickness does not influence the quantity of electricity, that depending upon the surface exposed to the fluid; but, if the metals be so thin that they cannot carry the electricity, a diminution in the quantity of the current produced will ensue, similar to that which arises from thin wires, simply because a resistance is afforded to the galvanic circuit. For this reason, earthenware coated with platinum was not found to answer for the negative plate of a Grove's battery, the platinum surface not being of sufficient thickness. Yet, however thin a metallic or good conducting surface be employed, the current will gradually traverse it; a property of no small importance for the electrotype.

(32.) As the metals are good conductors, and the metallic oxides non-conductors, it is important that the negative metal

should expose a clean metallic surface, or else it will be perfectly inert; therefore, when the old forms of batteries are employed, the copper should be thoroughly cleansed from oxide before the battery is put in action.

(33.) When the metal is thoroughly cleaned before it is employed, it still very speedily, in fact, almost instantaneously, loses its power. Now this depends principally, if not entirely, in a single battery, upon the hydrogen's adhering to the negative metal, which thereby becomes coated with a non-conducting surface of hydrogen, and is therefore rendered inoperative. The state of surface influences this adhesive quality.

The reader may readily convince himself of the truth of this. Let him immerse in a tumbler of dilute sulphuric acid a polished plate of copper, and then place a piece of zinc in contact with the copper below the surface of the fluid. Bubbles of hydrogen will speedily appear upon the surface of the copper, and will soon cover its entire surface. It will be seen that these bubbles, instead of rising to the surface, and escaping as soon as formed, (or in other words being evolved,) will continue adhering to the metal. This depends upon the principle called heterogeneous adhesion, which can only operate when the surfaces of bodies are brought into very close contact. A smooth surface of metal favours the adhesion of the gas to such an extent as to counterbalance the force with which it tends upwards to the surface of the fluid. This, considering the difference of specific gravity between hydrogen and water, can by no means be a trifling force. Mechanical roughening by sand-paper obviates in some degree this annoyance, but is by no means entirely a remedy. The mode of overcoming this adhesion will be treated of when we describe my battery. To give an idea of the amount of hydrogen which will adhere to smooth metals, I have frequently seen platinum, the heaviest of all substances, rise, by the force of the hydrogen, to the top of the water, after it had been in contact with zinc.

(34.) The same observations apply to the positive metal; for, if even impure zinc be polished, the hydrogen will yet adhere to such an extent, that scarcely any action will take place till the surface is corroded, when it will immediately become violent. There is another mode, however, of overcoming this local action, which has been adverted to in this place, instead of mentioning it before, because I believe its action depends upon the facilitating the adhesion of hydrogen; this mode is the amalgamation of the zinc by mercury. In making a battery this should never be neglected, from its economy, as but a small quantity of mercury is required. It is effected by acting upon the surface of the zinc, either by acid, or by planing the oxidized surface and then rubbing it with metallic mercury. Practically, plates of zinc are placed for a short period in dilute sulphuric acid, when metallic mercury is well rubbed over them. In conducting this operation the workmen should be taught to endeavour to make the zinc absorb as much of the quicksilver as possible, and in the long run that will be found to be the most economical. Let us never forget to whom we owe this discovery, which of itself enables galvanic batteries to be used extensively in the arts. Ages to come will perhaps have to thank the inventor, whom we are too apt to forget because he was neither on the council of the Royal Society nor a London Professor, yet still the obligation from the public to Mr. Kemp is the same.

The explanation which I have ventured to give of this valuable improvement is the following; the mercury envelopes the small portions of charcoal and foreign metals, and therefore the first gas evolved adheres so firmly to these, that every foreign point of metal becomes coated, so as to prevent farther action; for, of all the metals known, there is none to which the hydrogen sticks so firmly as to mercury. A very instructive experiment proves that the absence of action depends on the adhesion of the hydrogen; for, if mercury

with zinc dissolved in it, be placed in dilute sulphuric acid, it will give off no gas, but will be covered with large bubbles; but if a little sulphate of copper, nitrate of silver, or nitro-muriate of platinum be placed in the acid, an instantaneous change ensues, for the hydrogen has not now to be evolved, but is absorbed in the nascent state, to reduce the oxides of these metals. The protective influence which mercury exerts upon zinc is only operative when the hydrogen has to be evolved and not absorbed; thus it is but little protection to zinc when placed in dilute nitric acid, because the nascent hydrogen is absorbed by the nitrous acid, and does not infilm the zinc. This fact may be readily observed if two pieces of amalgamated zinc be taken of similar size; when one is placed in dilute sulphuric acid, and the other in the dilute nitric, the degree of action upon the zinc will be found to be far greater in the latter than in the former case. In fact, in dilute sulphuric acid, zinc well amalgamated will last for days, or even weeks, without suffering any important loss. These observations clearly indicate the necessity of abstaining altogether from the use of nitric acid, when we are desirous of obtaining the galvanic power at the lowest cost.

(35.) In an elementary treatise it is unnecessary to enlarge upon these views, but those desirous of entering into them can consult the Philosophical Magazine for April 1840, or the Transactions of the Society of Arts for that year. An observation of these facts led me to construct the Chemico-mechanical battery, of which we shall speak after we have described the other forms. Before, however, entering upon that subject, there is still another property of metals which has not been adverted to; viz. that the least oxidable metals, as platinum, in common with the metals which have most affinity for oxygen, become coated, or so infilmed with air, that they are rendered useless, because they expose a film of badly conducting substance to the fluid instead of a metallic

one. The film may be instantly destroyed by heat, or by strong nitric acid. This fact has been long known, and the familiar experiment of causing iron filings to swim, while magnesia, which is an impalpable powder, sinks, is an example. But I believe it had not been noticed as influencing galvanic effects till mentioned in the paper before quoted.

(36.) The mode in which the hydrogen is evolved, is supposed to influence the power of the battery; for, if removed from the negative metal in the nascent state by any substance which readily yields oxygen to combine with it, this power is greater than when it is evolved. The cause of this is not exactly known; some supposing that it arises from chemical action at both poles of the battery, whilst others explain it by supposing that the hydrogen carries off a certain portion of electricity of tension, as they find that a gold leaf electrometer is affected when brought near the evolved hydrogen.

(37.) No farther improvement was made in the galvanic battery hitherto described; all previous alterations being as to size or form, as flat cells, round cells; or as to the arrangement of the metals, as to which should be innermost: but these can scarcely be called improvements. At length Professor Daniell turned his attention to the subject, and produced a battery on a principle altogether new.

(38.) The form of battery which he recommended was from eight inches to two feet in height, and four inches in diameter. The outer vessel is to be made of copper, of which the external part may be painted, as it plays no part in generating electricity; while the inner remains uncoated. Into this cylinder a solution of sulphate of copper is to be poured, instead of the dilute acid used in previous batteries; but now, if a *zinc* plate were put into this solution, and contact were made, the copper of the solution would be reduced upon the zinc as well as on the outer cylinder, and thus great waste would ensue. It therefore became necessary to enclose the zinc in a porous vessel, in order to separate it from the sul-

phate of copper. This was effected by a piece of the gullet of the ox; and into this, which forms an inner vessel, the zinc, with dilute sulphuric acid, is to be placed. Thus we have an outer copper cylinder (C) with a solution of sulphate of copper (S), and an inner porous vessel (P) containing zinc (Z) and dilute acid (A). As soon as contact is made, the zinc is dissolved, and sulphate of zinc is retained in the inner part of the vessel; whilst, instead of the hydrogen being evolved at the negative metal, it reduces the copper from the sulphate of copper. The inner vessel must be looked upon as a disadvantage, because there is no doubt that it lessens the power of the battery by materially increasing the resistance. The more porous this vessel is, the greater is the quantity of electricity developed; and so common brown paper, coarse canvass, and porous earthenware tubes are employed, instead of the bladder, or the lining membrane of the gullet or intestines, as formerly. Professor Daniell uses for his positive metal cast zinc rods, which he amalgamates; and, as a little copper always passes through the porous vessel, this should be repeated every time it is employed. The earthenware tubes immediately after use should be plunged into water, and there kept till all the sulphate of copper is dissolved out; or else, by crystallization, it will sometimes disintegrate the vessel.

Fig. 1.

(39.) Many have thought that the zinc being two inches apart from the copper is too far, and they have used cylinders which approached a great deal closer; but although there is no doubt that by these means increase of power is obtained by lessening the resistance, yet many more inconveniences attend their application than the employment of the form originally suggested by Professor Daniell. In the use of porous tubes of every sort, whenever the reduction of a metal takes place, care must be taken that neither of the plates of the

battery touch the porous vessel; for otherwise the reduction of the metal will take place upon it, and at length a line of continuity will extend from one to the other. One form of Daniell's battery has been much used by Professor Wheatstone for his telegraph. It consists of a small outer vessel, containing the solution of sulphate of copper, and the piece of copper forming the copper negative plate. The porous tube is a little porous cell about the size of the end of a man's thumb. This contains the acid solution, and at the bottom an amalgam of zinc and mercury, which serves for the positive element. Professor Wheatstone finds this to be the most constant arrangement of the battery. Candidates, ever anxious to obtain the fame of a new invention, made this battery square, oblong, parallelopiped, and even in many other forms, without any real advantage; for all the alterations, attended with benefits one way, have counterbalancing disadvantages.

(40.) This battery is principally valuable for its constant effects; that is, for the power which it possesses of generating exactly the same amount of electricity for a long time together; and for this reason it is extremely valuable in many experimental researches.

(41.) To obtain its constant effects, however, certain precautions are required; for if we alter the resistance of any part of the voltaic circuit, whether in the cell of the battery or without it, the amount of electricity passing will vary: thus, if the size of the wires used for the communication be altered, or their length either materially increased or diminished, then will the quantity of electricity vary. The distance between the poles, and also their size, must remain the same, and great care must be taken that the porous tubes be of the same texture; for it is to be remembered, that if but one bad earthenware tube be used in a battery of large series, the quantity of electricity will be influenced throughout.

(42.) Much misunderstanding has arisen from the use of the term constancy; it is often thought to signify long-con-

tinued action, whereas these properties are really different; for a battery may be constant, but only remain in action for a short period; and again, a battery might continue in action for years, and not be constant in its action: the property of long continuation, however, is by far the more valuable.

(43.) The principal disadvantages of this battery are, first, the length of time required to set it in action; secondly, the trouble and expense attending the use of the porous tubes; and lastly, the necessity of continually re-amalgamating the plates.

(44.) The essential advantage which this excellent battery possesses over all which preceded it, is the removal of the hydrogen, instead of its evolution at the negative vessel, whilst in the nascent state, by its decomposing the sulphate of copper. It is owing to this, also, that this battery gives off no fumes. To employ its decomposing effects on acidulated water with the greatest advantage, a series of ten or twelve is required.

(45.) Another battery, upon precisely the same principles, although applied in a very different way, was invented by Mr. Grove. He uses, for his negative metal, platinum (P), and in the inner porous cell he puts strong nitric acid (N), and in the outer vessel, with the zinc (Z), dilute sulphuric or muriatic acid (A). The form which Mr. Grove prefers is a many-celled trough, like the Wollaston's, with flat parallelopiped porous tubes in the interior; and, as platinum is an expensive metal, he takes care that the whole surface is brought into full operation, by completely surrounding it with zinc. In this battery the nitric acid is decomposed by the hydrogen, and deutoxide of nitrogen is evolved; which, coming in contact with the atmospheric air, is converted into nitrous acid.

Fig. 2.

(46.) This battery is remarkable for its power; a series of

four being sufficient for most decompositions. A large series exhibits the arc of light in a very brilliant manner; for showing this phenomenon it exceeds all other batteries. This battery however, with its great intensity, is not without some serious disadvantages; for the nitrous fumes which are evolved during its action are extremely pernicious to the animal economy, so much so that it might be even dangerous to be exposed to them without a free access of air. These nitrous fumes will attack almost every metallic surface with which they come in contact, and therefore it should not be employed in a room where there are polished stoves or metallic apparatus. The nitric acid moreover passes through the porous tubes, and attacks the zinc to a considerable extent, independently of that zinc which is dissolved to generate electricity; and lastly, this battery has the objection of requiring the trouble and expense attending upon porous tubes.

(47.) We have thus seen that Mr. Grove's intense battery is in its principle similar to that proposed by Professor Daniell, for in both the hydrogen is removed by chemical means; in the first instance by nitric acid, and in the second by sulphate of copper. It possesses a great advantage by having one of the best fluid conductors we are acquainted with; for the nitrous acid formed during the action of the battery has been found by Dr. Faraday to possess this valuable property in a most eminent degree. Of course there are many other modes by which the same results may be obtained; as, for instance, by using nitrate of silver, or the salts of gold, palladium, and platinum, or by other oxygenated acids, as the iodic, chloric, and bromic. I have tried many other substances upon this principle, but have not arrived at any new result, nor have found any arrangement superior for its power to that of Mr. Grove.

A new substance, to be used in a similar manner, has lately been brought before the Chemical Society, a society which pro-

mises to give a great impetus to chemistry in this country. It is the dichromate of potassa, a solution of which is placed on the negative side of the battery, whilst dilute sulphuric acid is used on the zinc side. Now the zinc is dissolved on the outer side of the battery by the dilute sulphuric acid, and the dichromate is decomposed at the negative end; by which means, as in all diaphragm batteries, you incur a double expense without any advantage as to power, but with a slight sacrifice of space, and, in fact, by burning your candles at both ends. The ingenious application of this salt was first made known by Dr. Leeson.* Mr. Grove's battery, charged with potash, instead of nitric acid, also forms a powerful instrument.

(48.) In conducting a series of experiments on the ferrocyanuret of potassium, having had frequent occasion for the use of a galvanic battery, I found that although the two last were admirably contrived instruments, yet that it was very desirable to possess one that could be set in action at a moment's notice, and with comparatively little trouble. It became thenceforth my endeavour to construct one that should require little or no labour in its employment, and this was followed by devising the Chemico-mechanical battery.

(49.) This battery, after I had minutely investigated every property which belongs to the metals of which batteries are constructed, was made upon noticing the property which rough surfaces possess, of evolving the hydrogen, and smooth surfaces, of favouring its adhesion. Thus, whatever metal we use for our negative plate, we take care that it be roughened, either by a corrosive acid, as iron by sulphuric acid, copper and silver by nitric acid, or mechanically, by rubbing the surface with sand-paper. Even by these means the metals are rendered much more efficient; but, to take advantage of this principle to the fullest extent, I cover platinum with finely divided black powder of platinum, by galvanic means;

* A Daniell's battery, charged with dichromate of potassa, instead of sulphate of copper, forms a Leeson's battery.

that is, I place the platinum as the copper is placed in a Daniell's battery, but, instead of employing sulphate of copper in the outer vessel, I use a small quantity of nitro-muriate of platinum, so that the finely divided metal is thrown down on the sheet platinum previously roughened by sand-paper. In this way it was also placed on palladium, silver (roughened by nitric acid), plated copper, iron of every sort, and on charcoal, with the same good result; but no other metal was found to answer for its reception. The metal generally employed is silver, because of its cheapness and its not undergoing any alteration. But whatever metal be used, the principle is the same, viz. the affording a surface to which the hydrogen shall not adhere, but from which it shall be evolved; and the infinity of the points which are presented by such a surface as above described, appears to be the cause of this excellent result. The preparation of the silver is now made a separate branch of a trade, and perhaps it is the first application of the decomposing power of the galvanic battery which was publicly sold. The platinized metal can now be bought ready for use; but, for those who desire to perform this operation, a brief description is here added.

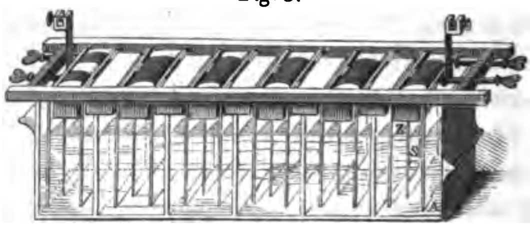
(50.) The metal to be prepared should be of a thickness sufficient to carry the current of electricity, and should be roughened, either by sand-paper, as in the case of platinum or palladium, or, when silver is employed, by brushing it over with a little strong nitric acid, so that a frosted appearance is obtained. The silver is then washed, and placed in a vessel with dilute sulphuric acid, to which a few drops of nitro-muriate of platinum are added. A porous tube is then placed in this vessel, with a few drops of diluted sulphuric acid; into this the zinc is put. Contact being made, the platinum will in a few seconds be thrown down upon the surface of the silver, as a black metallic powder. The operation is now completed, and the platinized metal ready for use. However, iron, when thus prepared, is as effectual as silver, and

may be sometimes employed with advantage. With this metal, all that is required is to rub a little nitro-muriate of platinum over it, and an immediate deposit of the black powder takes place. Palladium and iridium are found nearly as effectual as platinum to coat other metals with, and the platinized silver of commerce usually possesses a considerable quantity of this latter metal. Within the last few months an idea has prevailed in the minds of some, that wire gauze might be used with advantage; but it is difficult to conceive where the benefit would lie, for the cost of the material would be greater, the surface for the same weight of metal would be less, and neither space nor power gained by its adoption.

(51.) The liquid generally adopted to excite this battery is a mixture of one part by measure of sulphuric acid, and seven of water, which will be found amply strong for all purposes. Where we desire greater intensity, we can obtain it by the addition of a few drops of nitric acid; but, if too much be used, it might attack the silver. When, however, platinized platina is employed, the nitric acid may be used with impunity. The electro-metallurgist will frequently find it advisable to use dilute sulphuric acid, only containing from 1-10th to the 1-16th of the pure acid, and adding some acid when the first is exhausted; taking care, however, that the quantity of acid never exceed the 1-4th of the original water, for any excess above that quantity will be useless, as the liquid will then become saturated with the sulphate of zinc (19). The zinc, acid, and water being severally required to excite the battery, it is possible to regulate them that they should all be exhausted at once, so that the zinc should neutralize the acid, and the resulting sulphate of zinc exactly saturate the water. This however may be very interesting in principle, but practically it would be impossible to act with such precision; yet we must never forget this fact whenever we charge our batteries.

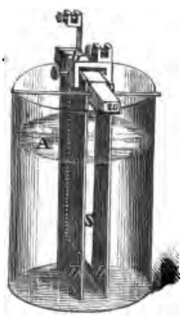
(52.) Numerous inquiries have been made as to what arrangement is best suited to this battery; but this must depend upon the purpose for which it is employed. For the student's laboratory the porcelain trough of many cells appears to be best adapted; and it is sometimes so constructed, that any number of cells can be employed, independently of the others, as they may be required. The silver being the most expensive metal, the zinc should completely surround it, so that the whole of the silver may be brought into action. Where a

Fig. 3.



battery is required to continue in action for a very long time, as for days or even weeks, a larger vessel, to contain more dilute acid, must be used: for electro-metallurgical purposes it has been hitherto found most economical to use a vessel of a size sufficient to hold liquid to last for seven or ten days. The form of battery now most universally employed for these purposes, consists of a piece of silver (s), on the top of which is fixed a beam of wood (w) to prevent contact with the silver. A binding screw is soldered on to the silver to connect it to any

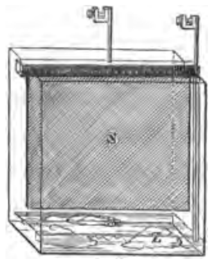
Fig. 4.



required object. A strip of zinc, varying at the fancy of the operator (z) from one half to the entire width of the silver, is placed on each side of the wood, and both are held in their place by a binding screw (b) sufficiently wide to embrace the zincs and wood. These batteries vary from the size of a tumbler to a ten or twelve gallon vessel. In the very extensive application of this battery to the arts, the little pieces of zinc which remain undissolved

in the battery form an important consideration to the manufacturer. Some distil the mercury from them, others sell them to the zinc works, whilst others have never turned them to any account at all, waiting patiently, in the hope that some more beneficial application of them might be discovered. These latter have hundred-weights of odds and ends in hand which they are desirous to employ. After considering the matter carefully, I have to propose the following use for them; in fact, I make them the positive pole of a battery, by placing them at the bottom of a vessel and covering them with mercury. A silver wire is then placed down a glass tube into the quicksilver, so that the wire may nowhere touch the dilute sulphuric acid, with which the vessel is filled, but simply make a good metallic communication with the mercury. At the other end of the wire a binding screw may be attached for the convenience of the operator. The platinized silver plate (s) is then to be immersed in the fluid, and placed as near to the mercury as possible, without actually being in contact, whilst no part of it should be more than three inches from it, as a considerable reduction of power would then ensue. This form of battery may be fairly called the Odds and Ends Battery, and though not so philosophical an instrument in its construction as the form last described, yet no manufacturer should be without one to use up the scraps from his other batteries; and I must say this instrument requires less trouble in its manipulation than any other form I have ever seen. An odds and ends compound battery, which will only require a binding screw at each end, may be made by placing the mercury and zinc at the bottom of a many-celled porcelain trough; the platinized silver should be cut into suitable squares, leaving a narrow slip to connect it with the next cell. The strip must be placed in a glass tube, or covered with

Fig. 5.



any non-conducting substance, leaving the end only to dip in the mercury of the next cell. A series of little glasses may be used instead of the many-celled trough for some purposes. The only objection which I have found in this form of compound battery, is the possibility of the zinc in one cell being completely exhausted, when the silver wire will begin to dissolve; in all other respects it is a delightful instrument when you do not care about obtaining the maximum of power, and you can obtain the galvanic principle by this means at a lower cost than by any other way. The odds and ends battery is admirably adapted for gilding and plating, or it may be employed for any operation that requires much time for its performance. The charge for this battery might contain one-third by measure of strong sulphuric acid, as the local action is very trifling; but it is found more advisable not to employ the solution so strong, as, when nearly exhausted, the sulphate of zinc will sometimes envelope the zinc and mercury, and prevent farther action before the top part of the liquid is fully saturated. An advantage of this instrument is, that spelter, or raw zinc, may be used instead of manufactured zinc, and that no mercury is wasted, as the whole is left after the solution of the zinc.

(53.) When we desire to employ a battery for manufacturing purposes, it might be as well in some cases to remove the sulphate of zinc as soon as formed, by means of a syphon tube passing to the bottom of the vessel, while fresh acid is continually supplied at the top; but this is not generally necessary. For these purposes the battery should be so constructed, that any of the zinc plates, when worn out, can be readily replaced. There are many other forms which may be adopted; as the circular, with the zinc outside; or it may be used as a tumbler battery.

(54.) The characteristic of this battery is the great quantity of electricity produced, and its simplicity; moreover, it requires but very little trouble in its manipulation. The zinc

seldom demands but one amalgamation, as that will generally last till the metal is all dissolved. It is very important to use for batteries zinc as pure as possible, for by that means the chance of local action is materially lessened. The manufacturers of zinc plates have a trick which is very fatal to this metal, for they buy up the refuse or waste pieces which frequently contain solder, a composition of lead and tin, and melt them with the raw zinc. This mixture always tells its tale during the action of the battery, as a light spongy flocculent precipitate rises to the top of the liquid which is metallic tin, and when any particle touches the zinc a little local battery is formed, which causes great waste of metal.

(55.) In using this battery it is important that no salt of copper, lead, or other base metal be dropped into the exciting fluid, as by that means the silver would become coated therewith; the plain consequence being, that a surface of copper, instead of that of the finely divided platinum, is presented to the fluid. From a want of knowledge of this fact, in some who have used the battery, I have seen the negative metal covered with copper, which finally becoming oxidated rendered the platinum useless. When this takes place, it is best removed by immersing the plate in dilute sulphuric acid, to which a few drops of nitro-muriate of platinum should be previously added; by this process the baser metals are dissolved and metallic platinum thrown down. Some manufacturers prefer dipping the silver into a solution of this sort every week. In this battery the zinc is never reduced upon the negative metal, from the sulphate of zinc formed during the action of the battery, so long as the exciting fluid contains any acid at all. Other interesting matter connected with this subject will be detailed when treating of the reduction of zinc.

(56.) Such is a brief view of the three batteries now in use: Professor Daniell's excellent invention being distinguished by its constancy; Mr. Grove's powerful battery, by its intensity; and my own, by the cheapness with which the quantity of

electricity may be developed, and by its simplicity. Neither of these can be regarded as a perfect galvanic battery, for each wants some of the properties of the others; it is to be hoped, therefore, that every attention will be given to the further improvement of these valuable instruments, until the good properties of each are combined in one. Which of the three is at present to be preferred, must depend upon the purpose for which it is required; and the choice must of course be left to the operator. For my own part, it affords me much pleasure to see that the platinized silver battery has fully answered the expectations which I formed of it; or even, I may say, in its extensive application very far exceeded it, as the amount of work already actually performed by this instrument is much greater than the total amount done by all other batteries ever since their first invention. By some it has been too much extolled, by others too much blamed. Notwithstanding the mis-statements on both sides, it has fully stood the test of time, and has been employed by the public in a manner which I had not even hoped. The reason they prefer it for general and especially for manufacturing purposes appears to be, that it does not require the use of porous tubes, nor of the strong acids, and that it does not give off poisonous fumes. It usually continues in active operation for six, eight, ten, or more days, when a sufficiency of acid is supplied to it. The zinc frequently demands but one amalgamation; and the time required either for setting it in action, or for maintaining its operation, is comparatively not worth a thought; and lastly, the expense of working it is reduced to the lowest possible amount, being exactly proportionate to the power obtained. With regard to the choice of the battery, it appears to me that he must be a clumsy operator who obtains the galvanic principle and cannot apply it; therefore the whole subject under consideration may be summed up by ascertaining with what battery the greatest amount of the galvanic fluid can be obtained at the smallest cost, the least labour, and the greatest

convenience. These three batteries agree by being each excited by the action of zinc upon water, the formation of oxide of zinc, and its subsequent removal by the sulphuric acid forming a sulphate of zinc: now, as this same salt is formed in each battery, the same quantity of water to dissolve the sulphate of zinc will be required to produce any amount of work, and therefore, whether Grove's, Daniell's, or my own battery be employed, the same sized vessel must be employed; proving the fallacy of attempting to obtain a battery where sulphate of zinc is formed in a small compass. In Grove's and Daniell's battery, however, if the diaphragm be of a nature that precludes the free passage of the zinc to the side of the platinum or copper, then will the amount of action depend upon the capacity of the vessel in which the zinc is immediately placed, and in that case a much larger vessel will be required for theirs than for mine.

(57.) Perhaps I may be expected to give an approximation to the relative cost of working the three batteries. In mine it is the cost of the zinc dissolved by the acid: zinc + acid + a local action. In the constant battery it is zinc + acid + sulphate of copper + much local action. Each cell of this, to do any given amount of work, would cost about twice as much as mine. In Grove's battery it is zinc + acid + nitric acid reduced by the hydrogen + nitric acid combined with ammonia formed during the action of the battery + extensive waste of the zinc = about three times as much as mine.

(58.) The construction of all the various forms of galvanic batteries has now been considered, and the principles also on which the peculiarities of each are founded have been briefly explained; though, if this important branch of our subject were to be alone discussed at a length proportionate to its value, this volume would not be sufficient for the interesting and important matter relating to it.

CHAPTER II.

ON THE PROPERTIES OF GALVANIC BATTERIES.

(59.) After describing the various forms of the galvanic battery, we are led to consider the effects which they produce; for these are called the galvanic effects, and the theoretical principle which causes them is termed galvanism.

The sign of a battery in action, is the change going on in each cell of the battery itself. In Daniell's battery it is evinced by a deposit of copper on the negative metal; in Grove's battery, by the evolution of nitrous fumes; and in mine, by an evolution of hydrogen. These several actions mark exactly the quantity of current passing; but in the two former batteries no accurate measure can be readily made, although in the latter the hydrogen may be collected in one of the cells by means of a glass jar, and the quantity thus exactly ascertained.

This property in my battery is of extreme value to the mechanic and experimentalist, for he can tell at once by the hissing of the hydrogen, whether the connections are all correctly made, and what amount of current is passing; a fact

of no small importance when used by the electro-metallurgist.

(60.) The next phenomenon which a battery displays is the power of heating conducting substances according to the amount of current which is actually passing, and the resistance which they afford to its passage; and by this the most infusible metals, as platinum, palladium, gold, copper, iron and steel, may be instantaneously melted. The size of the wires melted will depend upon the quantity of electricity developed, while the length will depend upon the intensity of the current. Mr. Snow Harris has ingeniously taken advantage of this property to make an instrument for measuring the voltaic current. It consists of a fine wire passed through a delicate air thermometer, and the expansion of air shows the degree to which the wire is heated. This instrument is a valueless test, unless both thick and thin wires be used in two experiments, for otherwise but one property of the battery is estimated.

Conducting liquids may be heated in a similar manner. This fact may be seen in a great variety of ways; dilute sulphuric acid may be made to boil in a syphon connecting two vessels in which the poles of an extensive series of batteries are placed. Another mode of showing the same fact is to take a piece of string and moisten it with acid, and connect the extremities with the poles of a series of galvanic batteries, when it will begin to smoke and become charred from the heat produced. The same fact may be shown by drawing a fine tube to a capillary point, which is to be filled with dilute acid, and placed in a glass of the same fluid. An electrode of an intense galvanic battery is then to be placed in each vessel, when bubbles, probably of steam, will be found at the capillary opening, causing a series of little reports, which may be heard distinctly at a distance of seventy or eighty feet.

(61.) The next property which a battery displays, is its power of igniting metallic or charcoal points, when joined to

the two ends of the battery, and held so that they barely touch; a light is then exhibited equal in brilliancy to that of a little sun. This has been called the spark, and much controversy has taken place among the learned as to the distance at which the spark will pass. Some have asserted that it will pass through some distance; Jacobi, however, considered the distance to be extremely small; but Mr. Gassiot, with that liberality of spirit which alone is a sure test of a man's devotion to science, fitted up 100 series of Professor Daniell's largest batteries, but with them by the most delicate micrometer he could not discover that the spark would pass at any appreciable distance; on the contrary, this large battery would remain quite inert if the poles were separated by the distance of the thinnest film of paper. In a late number of the Philosophical Magazine Mr. Crosse has revived the inquiry by stating that by a very extensive series of water batteries in his own possession he has succeeded in obtaining the spark at a short distance. He proposes to enlarge his battery to 1000 cells, in order fully to determine this point. Since that period the experiment has been tried with 100 cells of Grove's battery, belonging to Mr. Gassiot; but the spark was not found to pass through the smallest interval, although a most brilliant arc of flame was obtained after the poles were connected and then withdrawn.

The spark seems principally to depend upon a combustion of fine particles of metal, and, when charcoal or hard gas coke is used, upon little points of it flying from one pole to another, so that one pole wastes away, and the other increases, till the flame becomes quite encased in a mass of carbonaceous matter. This has always been a serious obstacle to the adaptation of this brilliant arc of flame to practical purposes. The phenomenon of the spark requires a series for its production: and a number of Grove's batteries is best suited for this purpose. This arc of flame is singularly repelled or attracted by a magnet held in its vicinity.

(62.) The next property evinced by the galvanic battery is its power of charging a Leyden jar; but this is a property of little importance, and requires an extensive series of batteries to be used to effect this object.

(63.) Depending upon the same causes as the last, is the shock, which is a convulsive twitching in the muscles from the intensity of the battery. This singular effect requires generally a series. It is felt only when contact is either made or broken; but if a cut exists in the finger, a small series will illustrate this property.

When we desire to exhibit the effect of the shock upon a dead animal, a pin ought to be run through the skin at the head, and another at its hind leg; every time the poles of a battery are connected or disconnected with these, strong convulsions will take place. If the upper lip be touched with a piece of zinc, and the under part of the tongue with a piece of platinum, or *vice versâ*, a flash of light will be perceived when they are connected, whether the eyelids be open or closed. No explanation can be given of this singular circumstance. All these phenomena are termed the physiological effects.

(64.) A galvanic battery has the power of producing certain effects which are called magnetic effects, and the supposed principle of magnetism. To describe the term magnetism would be impossible, like galvanism, or electricity, because we are only cognizant of it by its properties. There are but two metals capable of being magnetic, and these are nickel and iron. The identity of magnetism and electricity has, like all other branches of philosophy, received many important additions from the indefatigable Faraday; but, although magnetism is fraught with interest, it will be foreign to the purpose of this work to enter farther into its important details than to illustrate the effects of galvanism.

(65.) The voltaic current, passing at right angles to a piece of iron, from which it is separated by any non-conduct-

ing substance, induces in it the properties which are termed magnetic; for, if another piece of iron be now held to it, it will be attracted. The more frequently the same current passes round the iron, the greater will be the power; and for this purpose it is usual to twist wire covered either with silk or cotton round the iron, in order that the same current may pass at right angles a great number of times. When the current ceases, from the connection with the battery being broken, a difference according to the nature of the iron is observed; for, if it be the pure malleable soft iron, all magnetism immediately ceases; hence iron so situated is termed a temporary magnet: but, if hard steel is used for the experiment, the magnetism indeed is not so powerful, but it continues for a very long period; hence in this state it is called a permanent magnet.

(66.) A permanent magnet, if suspended in such a way that it can vibrate, has one of its poles turned to the north pole of the earth, the other to the south pole; but, if a galvanic current be passed round this permanent magnet in the direction of its axis, the magnet will be instantly deflected at right angles from the current, and upon this principle an instrument has been constructed called the galvanometer.

(67.) The direction in which the needle is deflected is best remembered by a little device which Professor Daniell describes in his lectures; for by supposing that we ourselves are the conducting wires, and the electric current passes from our head to our heels while we are looking at the magnet, the north pole will be turned to our right hand. This ingenious device is applicable to every position, provided we are either above or underneath the plane of the needle.

(68.) Galvanometers are differently constructed, according to the delicacy of the experiments for which they are required. In general it is sufficient to use a needle centred as if it were to be used for a mariner's compass, and a long covered wire is to be passed alternately over and under it in the

direction of the long axis. The two ends of the wire may be connected to mercury cups, to afford a ready means to unite them with the poles of the battery.

(69.) A much more delicate form of galvanometer is constructed by using two needles, so suspended that the north pole of one is over the south pole of the other.

The polarities are thus neutralized, and no longer under the influence of the earth's magnetism. In this state they are called astatic, and are generally suspended by the finest fibre of silk, so that the slightest voltaic current will act upon them.

It is advisable to allow one needle to have a slight preponderance, in order that the long vibration may not be troublesome. An instrument like this is only necessary for the most minute experiments.

(70.) Another form is termed the tortion galvanometer, because a resistance is afforded by the twisting of an elastic substance. By this we are enabled to appreciate differences in slight currents.

(71.) However useful the instrument may be for all small currents, large quantities of electricity are seldom measured by magnetic effects; but I believe that the right use of the magnet is a very important addition to our instruments for measuring galvanic currents. To estimate the quantity of electricity in any voltaic current, a piece of soft iron is to be bent in the form of a horseshoe, and a good sized covered copper wire is to be wound round it, the two ends being left free for connection with the battery. A piece of soft iron with a hook attached to it is to be used for the keeper, and the weight which this sustains indicates the amount of electricity.

This instrument is only valuable for comparative experiments, as different results will always be obtained by different magnets, because the quality of iron is found materially to influence the results; but if the same magnet be used, and

the wire of sufficient dimensions and of moderate length, there will be scarcely any appreciable resistance offered to the current; and the relative quantity of electricity evolved, independently of its intensity, can be accurately ascertained.

(72.) Temporary magnets are too frequently made with very thin covered wire, and even great lengths employed. Now, in this case, the amount of magnetism induced by any current ceases to be an exact measure of the quantity of electricity passing, because intensity is required to overcome the resistance afforded to the passage of the current from the wires; and it is from this cause that electro-magnetic engines, possessing, as they do, several magnets, and very often thin wires, require several cells before the current freely passes.

(73.) To give a comparative estimate of the value of this test of the quantity of electricity evolved, and of that whereby the power is estimated by decomposition, perhaps is premature, till the latter mode is fully entered into; but as the magnet requires but little intensity, or affords but little resistance to the passage of the galvanic fluid, and that entirely depending upon the size of the wires, it is apparent that one cell of each combination, or form of battery, will suffice for the experiment: if, however, the decomposition of water be taken as the test, a sufficient number of cells must be employed to overcome the resistance; and thus, if many combinations are made the subject of experiment, it will be attended with great inconvenience.

(74.) If the various effects which have been already described are fraught with interest and mysterious obscurity, how much more is the property, which the battery possesses, of decomposing various substances, and of overcoming the most powerful affinities by which bodies are united! To this part of the subject we are again indebted to the labours of which the Royal Institution has been the principal seat, and Sir Humphrey Davy and Faraday the authors, though

Daniell and many others have been by no means behindhand in the field of inquiry.

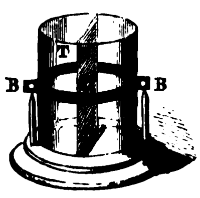
(75.) The decomposing cell is to be reckoned as one of the cells of the battery, with variation in the metals and solution for the purposes of experiment. Formerly the size of the plates of this cell was reckoned but of little importance, mere wires were employed; but now the plates are made much larger. This fact has been particularly insisted upon by Mr. Grove, and certainly it is a circumstance to be fully attended to. Throughout this work abundant instances occur of the importance of the size of the plates, poles, or electrodes in the decomposition trough, for there is not a single electro-metallurgical operation which may not be materially influenced by either varying the size of both poles, or by diminishing or reversing their relative surface. In some cases, indeed, where there is such a powerful resistance afforded by the evolution of the oxygen at the positive pole, this effect is not manifest; but even in that case, if it be reduced to a fine wire, I have seen a battery, capable of evolving 30 cubic inches of gas in five minutes, not able to evolve from the diminished surface scarcely one cubic inch in the same period. When a metal is used capable of combining with the oxygen, as silver or copper, then the size of the poles make important alterations, even if large plates are employed. We shall hereafter see that in the reduction of every metal these properties must not only be remembered, but acted upon, if we wish to perform our operations with success.

(76.) There are many forms of the decomposition cell which are useful, according to the purpose for which it is wanted. The simplest is the V-shaped tube, which is nothing but a glass tube bent in the shape of the letter from which it derives its name. A little strip of platinum is to be placed in either part with the fluid, and these are to be connected, one with the negative, the other with the opposite pole of the battery.

(77.) The next form was devised by Professor Faraday, and is adapted to measure the quantity of gas given off when water is decomposed. To this he gave the name of voltameter, as indicating the amount of electricity passing. Of this form there are many varieties, differing as a small or large quantity of gas is required to be measured. In the former case, two pieces of platinum are fixed about a quarter of an inch apart, and a tube, graduated to cubic inches, is supported over these poles so that the gas may be collected. Sometimes two tubes are employed, one over each pole, the object of which is to collect separately whatever may be evolved. In other cases, where large quantities have to be estimated, a bent tube passes from the top of the apparatus to a graduated jar placed in a pneumatic trough. Where great accuracy is required in the measure of the gas or gases evolved, they must be corrected hygrometrically, thermometrically, and barometrically, but this nicety would only be required for most delicate experiments. This instrument is made more complicated when the operator is desirous of investigating the changes which take place in the solution; for then porous tubes of earthenware, bladder, &c. are used to separate the poles, and to prevent the solution on one side passing freely to the other. Substances requiring heat to bring them into a state fit for decomposition are generally placed in a tube containing two fine platinum wires, which serve as poles when connected to the battery. A very useful form of decomposition apparatus is a glass tumbler (T) cut in half, and the edges ground smooth: between these any diaphragm (D) can be placed, as the two halves are kept firmly together and water-tight, by a brass band surrounding them (B).

Fig. 6.

Fig. 7.



(78.) Having described the usual apparatus to effect decomposition, we have seen that in every case they have in common two pieces of metal, separated from each other, but capable of being connected to either extremity of the battery. These pieces of metal have the mysterious and incomprehensible names of poles; one of which may be considered as holding the place of the negative metal, and is called the electro-negative pole; and the other, the electro-positive pole.

(79.) However, Dr. Faraday, disapproving of the name of poles, has called the electro-negative the cathode; and Professor Daniell, disapproving of both, has called it the platinode. These three terms, the electro-negative, cathode, and platinode, are synonymous, and are given to that pole which would have been the metal unacted upon, had it been in an ordinary cell of the battery. The opposite pole holds the same place in the decomposition cell as zinc in the ordinary battery, and technically has the name of the electro-positive, anode, or zincode of the battery.

Dr. Faraday has described the poles as the passages or doors by which the electricity enters into, or passes out of, the solution suffering decomposition. On this account he has given the term of electrodes. Good conductors are the best adapted for poles, and for this reason metals are generally employed; but poles of water, and even of air, have served this office.

(80.) The metal employed for Faraday's voltameters should undergo no change, either from the solution in which it is placed, or from the elements which may be evolved at its surface; and in this respect platinum answers above every other substance, for almost all other metals are liable to be oxidized, or even dissolved.

(81.) The greatest confusion has arisen by not considering the decomposition cell as one of the cells of the battery, but referring the effects to the plate of the battery to which the pole is connected. The reason of this is obvious; for, when

the terminal plates of a battery are connected with a wire, the circuit is completed, and the platinum of the battery is the platinode, electro-negative, or cathode of the battery. When the circuit is completed by a liquid to be decomposed, the effect is no longer to be attributed to the terminal plates of the battery, but to the plates in the decomposition cell with which they alternate; so that, as the free zinc of the battery is connected with the platinum of the decomposition cell, the name must not be given from the zinc of the battery, but from the platinum of the decomposition cell; and, therefore, it is the platinode of the battery. The converse of this applies to the extreme platinum of the battery; for, as the platinum in the decomposition cell with which it is connected holds the place of the zinc in the other cells, the platinum being substituted for zinc, to cause the evolution of the oxygen and to prevent its combination, the name must be given to the platinum in the decomposition cell, which is there holding the place of the zinc, and not to the terminal plate of the battery; it therefore is the zincode, electro-positive, or anode of the battery. Some have given a different explanation of this alteration of the poles, when the circuit is completed by a solution to be decomposed, instead of metallic wires; they suppose that the two terminal plates in a compound battery hold no farther place than that of carrying the current; but this will not bear the test of inquiry.

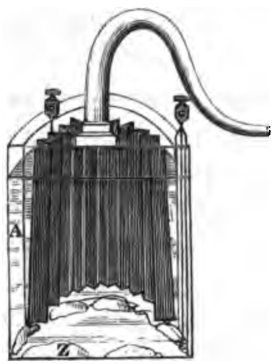
(82.) We have now seen that the decomposition cell, or decomposing apparatus, is nothing but one of the cells of the battery varied for the purpose of experiment; it necessarily follows the law, that in every cell there is a similar amount of chemical action. The measure of electricity by the chemical action may be made in any other cell in a great variety of other ways, such as by ascertaining the amount of the reduction of any metal at the negative pole, or the solution of a metal at the positive pole; for, wherever it is made, it will indicate exactly the action taking place. To Faraday these

important facts are due, which, perhaps, have given us a greater insight into the properties of the galvanic fluid than any other series of inquiries.

(83.) Of the value of the decomposition apparatus, or voltameter, it is necessary particularly to take notice. As far as the amount of chemical action actually passing is concerned, the voltameter is a most valuable test, being infallible. But if we are desirous of comparing the amount of electricity capable of being generated by combinations of different metals, or the effects which are produced by differences of arrangement, or the resistance which various substances offer to the passage of the current; then it must be recollected, that, if two platinum poles are employed, a strong resistance is offered to the passage of the current by the positive platinum pole, which would materially interfere with the accuracy of the result, unless that be overcome. In fact, the voltameter is an accurate test of what electricity actually passes in a galvanic circuit, but it does not at all indicate what might pass. A want of application of these facts has led many distinguished scientific chemists into singular blunders, and many circumstances have not been appreciated which would otherwise have been noticed.

(84.) A far better voltameter can be constructed by using one of the cells of the platinized silver battery, and collecting the gas evolved from the negative plate. This apparatus would offer but little resistance to the passage of the electricity, and would thus give more accurate results; but it has the disadvantage of itself generating electricity, thereby increasing the power. Practically, it is exceedingly difficult to compare exactly the power of any two batteries or combinations; for there are such a number of resistances in the galvanic circuit, and these vary with every battery, that it becomes quite a complicated mathematical problem to analyse the precise relative power of galvanic batteries. My battery voltameter is constructed in the following way: A bell-glass is

Fig. 8.



procured with a bent glass tube ground into the upper part to allow the gas to pass off to the pneumatic trough to be collected (A). In the bell-glass a piece of platinized silver is placed, which is connected by means of a piece of silver wire running through the glass to a binding screw outside the glass. The whole of the apparatus is plunged into another glass filled with dilute sulphuric acid, at the bottom of which is mercury and pieces of waste zinc; a silver wire connects this to another binding screw, to finish the connection when the apparatus is ready for use. This instrument is extremely valuable when we desire to measure the work done with a single battery, for it makes not only a voltameter, but the battery itself. When we are compelled to make an experiment with extreme accuracy, we might vary the apparatus a little, so that the hydrogen arising from any trifling action on the zinc may not be collected along with that obtained from the voltaic decomposition. The zinc in that case should be placed exterior to the inner vessel.

(85.) When we state that the action in each cell is alike, it is not meant that the same weight of metal or salt would be decomposed in each cell, but that one equivalent of some substance is decomposed in each cell: thus, for one grain of hydrogen liberated in one cell, 36 grains of chlorine would be liberated in a second, 96 grains of platinum in a third, and 200 of gold in a fourth, because these are the chemical equivalents, or combining numbers, of each of these separate substances.

(86.) The very term chemical equivalent seems to mark that it relates to something not very intelligible, and unfortunately that is found to be too correct, for this doctrine is

found by all beginners to be exceedingly difficult. However, by granting one supposition, the whole mystery is cleared up; for let us fancy that every elementary body is capable of being subdivided into ultimate atoms, and that the atoms of these are of different sizes and different weights, it will then be apparent that, if we group these atoms together to form any compound, we shall require different weights. Thus, if we combine gold with hydrogen, 200 grains of the first would take only one grain of the last, and yet there would be but one atom of each; or if one grain of hydrogen is liberated in the battery, 200 grains of gold would be deposited in the decomposition cell.

(87.) The following is a table of the equivalents of the substances which we shall have to speak of in this work; for our present purpose we may consider them as the weight of the primitive atoms. Thus, if we are able to ascertain the weight of zinc dissolved, of hydrogen evolved, or of the metal reduced, we shall be enabled to ascertain either of the other cases, or how much, either in weight or bulk, of any other substance would have been under the same circumstances thrown down:—

	Equivalent, by weight.		Equivalent, by weight.
Hydrogen	1	Silver	110
Oxygen	8	Nickel	28
Chlorine	36	Chloride platinum	132
Potassium	40	Chloride gold	308
Sulphur	16	Sulphate copper	125
Zinc	32	Nitrate copper, anhydrous	94
Lead	104	Sulphate zinc	143
Tin	58	Sulphate iron	139
Iron	28	Nitrate silver	170
Copper	32	Sulphuric acid	40
Gold	200	Nitric acid	54
Platinum	96	Muriatic acid	37
Palladium	54	Ammonia	17

As 100 cubic inches of hydrogen weigh 2 grains and 1-10th, it follows that, for every 47 cubic inches of gas evolved from my battery, 32 grains of copper, 96 of platinum, and 200 of gold, would be reduced; and the equivalent of every other substance would show in grains the quantity thrown down. I shall frequently use the term "an equivalent of galvanic power," by which is meant that amount of power which is necessary to cause the evolution of one grain of hydrogen, 200 of gold, &c.; therefore, whenever I use that expression, the grain will be taken as the standard, and it will be assumed that 47 cubic inches of hydrogen are evolved from my battery.

(88.) Next to the form of apparatus for decomposition, a description of the laws by which they are influenced follows as a natural sequence, and these have been fully investigated by the labours of Dr. Faraday. All bodies must be in a peculiar state to suffer decomposition, for no solids can be thus acted upon. When fused by heat they very readily give up these elements; as, for example, chloride of silver, which is decomposed by a single cell of zinc and platinum, excited by dilute sulphuric acid, though no voltaic power will separate them in the solid form.

There are apparent exceptions to this law, as the decomposition of sulphate of lime and baryta with the addition of water; yet the first of these is undoubtedly moderately soluble. The same perhaps cannot be said of the latter, though probably a little dissolves which is decomposed, and thus the fluid not being saturated dissolves more, and this is repeated till the whole is dissolved.

(89.) No fluid will be decomposed unless it be a conductor: thus pure water, which is a very bad conductor, does not yield up its elements; whilst if acids or alkalies be added to it, then it becomes a very excellent conductor, and is easily decomposed. Water may also be made a good conductor by the neutral salts.

As a general rule, fluids will not conduct an electric current without suffering decomposition; and for this cause, as soon as water is made a good conductor, it is decomposed, and the water does not conduct more electricity than is to be accounted for by the decomposition.

(90.) Some fluids, however, of good conducting power, may have a current of less intensity than is required for the decomposition passed through them; therefore these two laws, both developed by Faraday, are not exactly the converse of each other. Examples of the exception to the second are to be found in chloride of lead or fused nitre, which conduct feeble currents without decomposition.

(91.) A certain intensity is necessary to effect all decompositions, and this differs with different substances, according to the resistance they offer to the passage of the galvanic fluid; thus, a solution of iodide of potassium, or fused chloride of silver, yields to a single battery, whilst dilute sulphuric acid and other substances require more intensity to effect the same object.

The following, upon the authority of Faraday, is a short list of substances in the order in which they most readily give up their elements: —

Iodide of potassium, solution.
Chloride of silver, fused.
Proto-chloride of tin, do.
Chloride of lead, do.
Iodide of lead, do.
Muriatic acid.
Water, acidulated with sulphuric acid.

(92.) Some bodies suffer decomposition directly, as the consequence of the voltaic force passing; as water, which gives up its elements, hydrogen and oxygen, solely from the electric currents. To this Dr. Faraday has given the term electrolysis, because the elements appear to be rent from their combination directly by the voltaic force, in contra-distinction to

another important property, which will be hereafter mentioned. The elements which are decomposed he has called ions; they are not both evolved at one pole, but one at the electro-positive, anode, or zincode, while the other is given off at the electro-negative, cathode, or platinode of the battery. Those which pass to the first pole are called anions; those to the second, cathions.

(93.) The poles, or electrodes, have no attraction for elementary bodies as long as they are in a simple state, for bodies must be in combination to be affected by the voltaic current. Upon this account, a simple solution of chlorine, bromine, &c. does not give up these substances to either electrode.

(94.) Those bodies capable of suffering decomposition must contain one equivalent of each element, that is, composed of one of the hypothetical atoms, which have been previously mentioned (87); and to this general law but a single exception can be found in the periodide of mercury, which, however, is so unstable a compound, that the slightest exposure to light will cause its decomposition, which alone would be calculated to throw doubt on the validity of the experiment.

Sulphuric acid and phosphoric acids are not themselves electrolytes, that is, they do not directly yield their elements to the force of the battery, because they consist of one equivalent of phosphorus or sulphur to three of oxygen.

(95.) It is not necessary that a substance should be directly composed of elements to enable it to pass to the electrodes or poles; or, in other words, bodies composed of compound substances are ions, as well as those composed of simple substances: thus, sulphuric acid, phosphoric acid, arsenic acid, and other acids are ions to the electro-positive pole, or anode; while protoxides generally, ammonia, potassa, and many other substances, are ions to the opposite pole. The

following is a list of simple and compound ions given by Dr. Faraday: —

Anions:

Oxygen,	Fluorine,	Selenium,
Chlorine,	Cyanogen,	Sulphocyanogen,
Iodine,	Sulphur,	Acids,
Bromine.		

Cathions:

Hydrogen,	Alkalies,
All the metals,	Vegito alkalies, as morphia, &c.
Metallic oxides,	
The earths,	

(96.) The same substance, under different circumstances, will be evolved at different electrodes; as at one time it may take the part of a base, at another it will perform the function of an acid. A familiar example of this is afforded in the oxide of copper; for when combined with sulphuric, nitric, muriatic, or any other acid, it is evolved at the negative pole, or cathode; whilst, when in combination with ammonia, it acts the part of an acid, and is evolved at the anode or positive pole.

(97.) If we find a body at the pole of a battery, it is by no means certain that it has passed by direct decomposition of the voltaic current; because, if the compound of which it formed a part, was dissolved in water, the elements of the latter being set free, often act in an important way to form new combinations, which result from the secondary effects; thus an aqueous solution of a metallic salt, for instance, copper being subjected to a voltaic current, has hydrogen presented at the cathode, and oxygen at the anode. But at the same time this change is taking place, oxide of copper is passing to the cathode, and sulphuric acid to the anode. The hydrogen seizes upon the oxygen of the oxide of copper, and forms water, whilst the metallic copper is thrown down on the electrode or pole, not by direct voltaic action, but as a

secondary effect, attributable to the hydrogen. Sometimes the elements will combine with the poles or electrodes, forming new combinations; thus, if the poles be easily oxydated, the oxygen will form an oxide, and, in the same way, if any other substance be presented to the gases for which they have strong affinity, a similar combination will take place. Hence this class of effects, which are far more numerous than electrolytical effects, are called secondary, or electro-chemical decompositions. Sometimes these secondary results are most complicated, and perhaps none more so than the extraordinary one which I have described to take place with the oxygen, on the common yellow ferrocyanate of potash; as this, by combining with a portion of the potassium of the ferrocyanate, gives rise to a totally new definite salt,* whilst the potash so formed is carried away from the sphere of action.

(98.) The secondary effects of oxygen and hydrogen have been proved by numerous well-devised experiments, but still no positive demonstration was obtained, that the hydrogen evolved from the decomposition of water, would reduce the metals with the voltaic current. However, whilst experimenting on the non-metallic elementary bodies, the porous cokes and charcoal were observed to retain a portion of gas, after they had formed either the negative or positive pole of the battery.† When those which had been made the negative pole were afterwards plunged into a solution of sulphate of copper, they became immediately coated with the metal, adding positive confirmation to inductive reasoning. Coke charged with hydrogen retains this curious property for many days.

(99.) Professor Daniell, in a paper read before the Royal Society last spring, has given an entirely new view, as to the mode in which the metallic salts are sometimes decomposed. The professor found if a solution of a metallic salt was placed in a vessel, over which a piece of membrane was tied, and that inserted into another containing a solution of caustic

* Philosophical Magazine for September, 1840.

† Philosophical Magazine for May, 1840.

potash or soda, so that the membrane formed a sort of diaphragm between the two solutions, and then if the poles of a compound galvanic battery were placed into the two solutions, the positive into the metallic solution and the negative into the alkaline solution, that the metal of the first solution was deposited on the bladder. This is an experiment easy to repeat with several solutions, especially silver, mercury, and copper, though with gold and platinum the same result does not appear to take place. If acids or neutral salts be employed, instead of the alkaline solutions, I have never seen metal deposited on the bladder. When the alkaline solutions are used and the metal is precipitated, gas is always evolved from the membrane. In these cases a question might be raised whether the membrane between the two solutions might not become polar similar to interposed wires. Mr. Daniell supposes that in this experiment the acid and oxygen pass one way, and the metal the other. From these considerations he has given a new view of the composition of the salts: thus, sulphate of copper, instead of consisting of sulphuric acid + oxide of copper is supposed to be constituted of (sulphuric acid + oxygen) + copper. The two first elements, as they are considered to be in combination, are called oxysulphion, and the salt oxysulphion of copper. In the same way, the radicle of the nitrates is called oxynitrion — of the carbonates, oxycarbion—of the oxalates, oxalion — of sulphovinates, sulphovinion.

In the same paper, another important fact is detailed; which is, the property the electric current possesses, of decomposing two substances in the same solution; thus, both a metallic salt and acidulated water may be decomposed at the same time, the current dividing itself between them.

(100.) We have now seen that substances may be decomposed in two ways, either from directly yielding their elements to the voltaic current, when the compound consists of single equivalents, which is termed electrolysis, or, by a se-

condary action which occurs oftentimes; as a result of a new decomposition by or combination of the elements of the first substance decomposed, upon a second substance within the sphere, which secondary action is termed by Dr. Faraday Electro-Chemical Decomposition.

(101.) The fluid between the electrodes, whilst decomposition is taking place, apparently has no change; that is, the effects of the decomposition are only manifested at the poles; thus, if sulphate of copper be electrolysed, sulphuric acid passes one way, oxide of copper another; yet neither acid nor oxide can be found in any part intervening. These experiments are best conducted in a long flat vessel with two porous plates which divide it into three departments, of which the two exterior receive the electrodes.

(102.) The temperature at which the solution to be decomposed is kept, materially interferes with its conducting power; a fluid which is a good conductor at ordinary temperatures, will scarcely admit the passage of the galvanic fluid at the freezing point, whilst at the boiling point a passage will be afforded with the greatest readiness. It becomes, therefore, a very important matter to keep solutions at a high temperature, when we are desirous of effecting much decomposition in a short time, and at a slight expense.

(103.) The galvanic fluid, when it has the choice of a passage through various conducting substances, prefers that which affords the least resistance to the exclusion of the rest; thus, if a galvanic battery of large series is connected to a decomposition apparatus, and is capable of giving off 20 or 30 cubic inches of gas in five minutes, yet if the finest platinum wire is placed across the poles, the whole of the power will pass by the wire during the short time that it remains unmelted.

A curious property of induction is observed, under certain circumstances, in the voltaic circuit: thus, if a wire or a series of copper wires are suspended in a liquid which is

suffering decomposition, whether that be in one of the cells of a battery or in the decomposition apparatus, one part of each wire will be seen to become positive and be dissolved, whilst another part will be negative and reduce any metallic salt. This phenomenon will be seen to be taking place differently in each of the wires. If a platinum wire be interposed in the circuit the resistance which the evolution of oxygen affords is so great, that the polarity of the wire is only to be seen in certain cases. However, feeling assured that platinum could be made polar, I set to work with determination to effect it. I tried large plates of platinum in sulphate of copper, between two copper electrodes, connected with a powerful battery, but could not succeed; however, not to be beaten, I tried the experiment in a different way. A piece of fine platinum wire was fixed in a small tube, one part remaining in the inside, the other on the outer part of the vessel, a small hole was then left in the tube, of such a size that water could freely run out. The tube was filled with dilute acid, and placed in a glass full of the same liquid, when the pole of a series of batteries (not less than 8 cells) was inserted into the tube, taking care that it did not touch the wire fastened in the tube: the other pole of the battery was placed in the glass of dilute acid, when immediately gas was evolved from the two poles, and also from the platinum wire. It was then thought desirable to ascertain whether as much gas was evolved from the intermediate platinum wire, in which the gas was given off by induced electricity, as from the original poles. This point was determined upon the principles which regulate electro-metallurgical operations, for upon the addition of a small quantity of sulphate of copper to the acid, the pole connected with the zinc of the battery was coated with spongy copper, whilst the part of the intermediate platinum wire which became negative had the bright reguline copper reduced on its surface. The rest of the intermediate wire was positive, and evolved oxygen gas. It is a

econdary acti decomposi substanc sphere, Elect (1 sit t

"... interest to ascertain whether non-conducting substances could be made polar in a similar way, but all the evidence with me has varied sometimes one way and sometimes another; and I am quite uncertain whether they may be made polar or not. Of course the smallest portion of any solid conducting substance, as the smallest atom of charcoal or plumbago, will instantly become polar and give off gas. This kind of induction is interesting as explaining the action which takes place on a binding screw or piece of copper dropped into a galvanic battery, or into a metallic solution, which is being decomposed.

In this place let us recapitulate every circumstance which, by affording a resistance to the passage of the galvanic fluid, will lessen the amount of the action. In the first place, in the battery itself the current of electricity might be diminished by the metallic plates being too thin to carry the current readily. It may also be lessened by the plates being far apart, or the interposed liquid being an imperfect conductor. The negative metal may be covered with hydrogen and rendered nearly inert, or the positive may be rendered inoperative, by the saturation of the acid by the zinc, or the liquid by the metallic salt. External to the battery resistance may be afforded by small wires, or by connections of imperfect conducting power, or by attaching it to a decomposition apparatus, every part of the construction of which obeys the same laws as the galvanic battery itself.

The application of voltaic power to the arts is one of the greatest improvements of modern times, and although much has been done in this important and extensive field of inquiry, yet this alone suffices to show, that as we progress, the path to be pursued widens and enlarges, exposing to view an immense tract, fertile exactly in proportion to the labour and ability employed in its cultivation.

It was first discovered by Faraday that, upon making or breaking contact by a long wire with the galvanic battery,

another current was developed in a second wire, isolated from the first by some non-conducting material. Thus if we take a copper wire, say 60 feet long and one-eighth of an inch thick, and form it into a helix by winding it regularly round a hollow tube, and superimpose upon that a great length, say 1200 feet, of a very thin wire, covered with silk, cotton, or any such non-conducting material, and wound round the first wire in a similar direction, we form an apparatus that at once shews the experiment on making contact with the two ends of the thick wire with the plates of a galvanic battery; a current of electricity is generated in the second wire, and though the first current may be derived from only a single pair of plates, the second current may have amazing intensity, in fact, sufficient to give the most powerful shocks; a secondary current is produced on again breaking contact, but no second current is formed whilst the circuit is completed. These effects are far more exalted if we place a piece of soft iron, or a bundle of soft iron wires, into the tube round which the primary wire is wound, because we then add the powers of magnetic induction to that derived directly from the galvanic battery. A machine upon this principle is constructed in the manner above detailed, one end of the primary wire being connected to a metallic-toothed wheel, the other joining a flexible piece of brass capable of pressing the teeth. By revolving the wheel the contact is made and broken, according to the rapidity of the revolution, and thus hundreds of shocks may be transmitted in a minute. This induced electricity is invariably used at the present period for medical purposes, and by regulating the force of the battery and the frequency of the shocks, we can adapt our shock exactly to the state of the patient.

Such is a brief account of the leading effects which are called galvanic, with the various properties which are either subservient or detrimental to the voltaic current.

BOOK THE SECOND,

ON ELECTRO-METALLURGY.

CHAPTER I.

ON THE APPARATUS TO BE EMPLOYED FOR THE REDUCTION OF THE METALS.

Electro-metallurgy requires a knowledge of galvanism, 104. The idea of electro-metallurgy, suggested by Daniell's battery, 105. The porous tube or single cell apparatus, 106—112. Capillary tube apparatus, 113. Plaster apparatus, zinc, iron, and tin positive poles, 114. Compound battery apparatus; 115, 116. Single battery apparatus, 117, 118. Precipitating trough, 119. Single cell and battery conjoined, 120. Mason's arrangement, 121. Management of the apparatus, 122, 123. Lines on the reduced metal, how to be avoided, 124. Adhesion and non-adhesion of the reduced metal to its mould, 125—128. Apparent adhesion, 128. Lateral growth of the reduced metal, 129. Relative expense of various modes of the reduction of metals.

(104.) ELECTRO-METALLURGY depending essentially on galvanic agency, is subject to the operation of the same principles, and governed by the same laws which have already been laid down in the book which treats of galvanism and galvanic batteries; the successful reduction, therefore, of the metals, must depend entirely upon a thorough knowledge of galvanism, and galvanic apparatus. We should recommend our readers, then, before they enter upon this department, to make themselves thoroughly conversant with the contents of the first book; for what operation can be successfully performed without a complete knowledge of the nature of the implements with which that operation is to be effected.

Independently, however, of these general galvanic proper-

ties already adverted to, there are certain particular ones appertaining either to the different metals, or to the different qualities of the same metals, which have to be considered in detail, as well as the apparatus to be employed for precipitations.

(105.) The idea of electro-metallurgy appears to have been first suggested by the use of Professor Daniell's battery, for during its action the outer copper vessel, which is the negative metal, becomes coated with an additional layer of metallic copper; hence, as this new deposit is placed in close apposition to the vessel, a cast is produced. If we call to mind the construction of the battery, we see that it consists essentially of two vessels, the inner being porous, and containing dilute sulphuric acid, while the outer contains the solution of sulphate of copper, and the negative metal.

(106.) Daniell's battery is composed of two vessels in which two separate processes are going on; in one, the solution of the zinc, in the other, the reduction of the metal from the solution. In many cases the passage of the sulphate of zinc formed during the action into the other cell is not of much consequence; but when we are desirous of completely separating the two fluids, we use a diaphragm capable of effecting that object.

(107.) The substance best adapted for the complete separation of the solutions, in a single cell apparatus, is animal membrane. Of this there are various kinds; bladders of different textures, the lining membrane of the intestine of the ox, fine gold-beaters' skin, or bladders of various animals may be used according to circumstances. Animal membrane separates solutions better than any other diaphragm, but, for most purposes, it affords too much resistance to the passage of the current. There are a great variety of papers which may be used for porous tubes; they admit the current according to their relative textures. Brown paper, and cartridge paper, are frequently of value for the electro-metallurgist, and they last for

a considerable period without renewal. Of late, earthenware tubes have been very extensively employed. The kind of most value are made absorbent, similar to the vessels employed for wine-coolers, and are made of different shapes, to suit various purposes. The best are generally made with care and of superior clay, but the common earthenware garden-pots answer in some cases where porous vessels are required. In selecting a porous vessel we have to guard against two extremes; for, either it may be over fired, or baked at too great a heat, when it will not be sufficiently permeable by liquids, or it may not be sufficiently baked, when any metallic solution will act upon and partly dissolve its substance. We should, furthermore, always ascertain whether water will pass slowly, but entirely, through every part of its texture, in order that universal porosity may be proved. But the practised electro-metallurgist can always judge of the fact by touching it with his tongue, when the degree of dryness produced on that organ by the absorption of its moisture will indicate the freedom with which liquids will pass. A clayey appearance, and peculiar odour when placed in water, are the only tests of an imperfect baking. A common tobacco pipe, with the hole blocked up, is very useful for small experiments. Wooden porous tubes have been used by some persons; Jacobi makes mention of having employed them. They should always be boiled in acid before they are first used, to render them more porous, but no particular advantage attends their application. Plaster of Paris is sometimes employed, but it speedily becomes acted upon by the fluids, and upon the whole is not a useful diaphragm. Any vessel with a small fissure, or fine crack, in it, may be used as a porous pot, for any vessel which will let fluid run out will allow the galvanic current to pass. We have already mentioned, in a former part of the work, that the more porous this vessel is, the greater the quantity of electricity developed, and the greater, therefore, the quantity of metal deposited, as the amount of deposit is always

in relation to the quantity of electricity generated. The following is the order in which different substances stand with regard to their capabilities of admitting the passage of electricity :—

Brown paper,
Thin plaster of Paris,
Porous earthenware,
Gold-beaters' skin,
Bladders of various thickness,
Thick plaster of Paris,
Capillary tube.

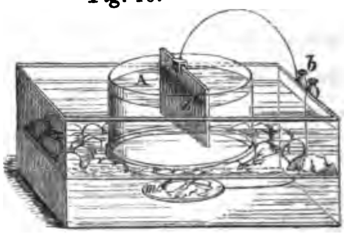
(108.) Of the various forms of apparatus, which may be used for the precipitation of the metals, the most simple is Daniell's battery, having a porous earthenware tube, to contain the acid and zinc, whilst the negative metal, which is usually a mould, is placed externally to this, and connected by a piece of wire to the zinc. Thus, for instance, take a pound pot, and half fill it with a solution of sulphate of copper (S); in this, place the earthen vessel (P), with the dilute acid (A) and zinc (Z), and this constitutes the whole of the present form of apparatus; for, when we desire to make an electro-medallion, it is only necessary to place one or more casts in the outer vessel (*m m*) connected by a wire with the zinc, and then action will immediately commence. Any number of moulds may be placed in the outer vessel, provided they can radiate to the zinc. Saturation of the liquid may be preserved by suspending some of the salt in a linen bag over the mould. This form is objectionable, because the salt of zinc speedily passes through to the outer vessel; but it has the advantage of allowing the mould to be placed vertically, in which position it is much less liable to have particles of dust settling upon it. There is no limit to the size of this outer vessel; for a water-butt, a tank, or even a lake naturally

Fig. 9.

impregnated with sulphate of copper, would form glorious apparatus for the electro-metallurgist.

(109.) There is another form where bladder takes the place of the earthen vessel, and where the position of the cast is horizontal. Here, the outer vessel, which is square, is made of wood, coated internally with cement; on one part of the edge of which, a piece of brass is fixed (*b*), in which are two holes, one for connection with the wire of the cast (*m*), the other with that of the zinc. In the interior of the trough, a moveable shelf of mahogany is placed, on which is supported a glass containing a zinc plate (z) and crystals of sulphate of copper to be dissolved. The glass has a piece of bladder tied over the rim, and this forms an outer vessel similar to the porous tube in the former apparatus. It, in like manner, contains the acid and zinc; the latter being connected by a screw to a wire, in such a way that it can be readily removed. This apparatus is preferable in many respects to that first described; because the sulphate of zinc cannot pass through the membrane readily to the copper, and facilities are offered for changing the zinc and acids, &c. In this apparatus, care must be taken that the mouth of the glass be wide enough to afford a radiating point from the zinc to every part of the cast, as it has been already noticed, that want of attention to this would be attended with inconvenience. (17.)

Fig. 10.

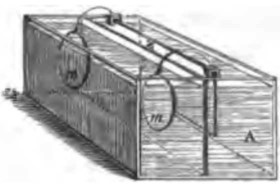


(110.) In every single cell apparatus, the solution of metallic salt should be maintained in the required degree of concentration, by keeping some crystals of the salt undissolved in the solution. If these crystals are allowed to sink to the bottom of the vessel, they will not answer the intended purpose of maintaining a saturated solution; for the portions of the fluid which have been deprived of their metallic salt

rise to the surface, whilst the saturated parts remain in contact with the crystals at the bottom, thus preventing their solution. This difficulty may, however, be readily overcome, by placing the crystals to be dissolved in a little bag, on a shelf at the top of the liquid, by which means the saturation of the fluid will be ensured.

(111.) Another form might be made by dividing a box into two compartments, by a flat porous slab of earthenware, similar in composition to the porous tubes of a Daniell's battery. Into one compartment the solution of sulphate of copper is to be put, together with the negative metal, which in the cut is represented by two moulds (*m m*), and into the other dilute sulphuric acid (A) and the zinc (Z). The advantage of this apparatus would consist in the facility gained in the manipulation; and in the arrangement of the positive and negative metals, so that they may be at every place equidistant from each other —a circumstance of great importance. The porous diaphragm, however, cannot be made of any large size, so, perhaps, it might be exchanged for a more ready, but less durable one of plaster of paris, paper, or bladder. The decomposition apparatus fig. 7, made of a cut tumbler, answers well for numerous experiments.

Fig. 11.



(112.) Other forms may suggest themselves to the operator, for in whatever way a Daniell's battery is constructed, a similar form will equally answer for the electro-metallurgist. (38.) The only circumstance to be observed is, that the zinc be equidistant at every place from the metal on which the reduction of the new metal is to be effected, so that the deposit may be everywhere equally thick. If the distance varies, the reduced metal will be found to be of unequal thickness, that part nearest the positive metal will be very thick, whilst the substance will diminish as it recedes from that point; in some

cases the effect is more apparent than in others, but occasionally where a mere rod of positive metal is placed opposite a large surface of negative, a complete convex mass is formed, gradually diminishing in thickness in every direction. In some cases these effects of radiation present some complex phenomena; but generally they may be referred to the fact, that the galvanic principle is not so essentially radiant, but that it will pass round a corner: thus, if a flat piece of copper is placed opposite to another mould in a solution of sulphate of copper, a portion of current is generated at every part of the back of the positive pole, which turning round the corner, causes a far greater mass of metal to be reduced at the circumference of the mould. At other times the effects of radiation are farther complicated by the imperfect uniformity of the strength of the solution during the action of the apparatus, in which case, every part not being equally conducting, will admit a different quantity of electricity, and, therefore, a different thickness of metal will be reduced.

(113.) An apparatus for very weak currents, I sometimes use with great advantage, when the change takes place at the cathode of the battery. It is made in a very simple manner: the solution to be decomposed, is placed in a tumbler; a piece of glass tube is then drawn at one extremity to a capillary bore. This fulfils the office of the porous tube, and contains the zinc (which in this arrangement is merely a piece of amalgamated zinc wire) and a very dilute acid solution. The quantity of electricity generated by such an arrangement as this, is necessarily very small indeed, for the construction is in every way unfavourable to its developement; first, the diluteness of the acid solution materially lessens the quantity; then, the hole through which the current has to pass is so small that much force is required to blow any liquid through the aperture, even by drops, and therefore a great impediment is offered to the passage of the current. Moreover, a very fine platinum wire is employed to effect communication;

and, lastly, the substance, which is the subject of experiment, is not placed opposite to the capillary hole. The mode in which the capillary tube acts in lessening the current, seems to be by interrupting or breaking the continuity of the fluids, so that but a feeble amount of the current can pass. The regulation of the quantity of electricity can be perfectly effected by regulating the bore of the tube.

(114.) Sometimes, when a very feeble current is required, a glass is filled up at one end with a thick piece of plaster, which fulfils the office of a porous tube. This apparatus was first employed by Dr. Golding Bird. Where we only require to lessen slightly the quantity of electricity, we content ourselves with extending the distance between the electro-positive and negative metals. In other cases we use a thick bladder or thin communicating wires, and we conjoin the whole or a part of these contrivances for lessening the power.

In the single cell apparatus up to the present time, zinc has been invariably used for the positive metal, and various solutions may be employed with the zinc; common salt has been much used, &c. The various sulphates and other neutral salts can be also employed without the amalgamation of the zinc, but if we go to the expense of this amalgamation, we may employ dilute sulphuric acid, or dilute muriatic acid, both of which, from their superior conducting power, enable us to reduce far more metal in a given time. Zinc in a single cell will reduce nearly all the metals, and, as it forms soluble salts with nitric, muriatic, sulphuric, acetic, tartaric acids, it may, therefore, be employed for all salts which contain these acids, for we must never forget that it is essential that the new salt formed should be soluble in water, and that a sufficiency of water be supplied for its solution.

Now having discussed the arrangements principally suitable to those cases where zinc is employed, as the positive metal, or metal used to generate the current, I have to impart the great secret, that it is not always necessary to use

zinc as the generator of the voltaic power, for, practically, it is possible in a great many cases, especially in the reduction of copper, to make iron take the place of zinc, thereby superseding the use of that expensive metal, and substituting one of but trifling value. But iron is not capable of imparting the same electro-motive power, intensity or primitive force of the galvanic principle that zinc is so eminently endowed with, for this reason we are compelled to use a greater extent of surface when iron is employed. Moreover, we have still other difficulties to contend with, iron cannot be amalgamated like zinc to stop local action, and, therefore, can only be used profitably with saline or other solutions that do not themselves act upon the iron when not forming a galvanic current. The apparatus the most suitable to the application of this metal is that which most favours an increase of the positive metal. A very simple form is a common cast-iron supply cistern, into which a parallelopiped porous tube, one inch smaller each way, might be placed, separated by two pieces of wood inserted at the bottom of the tank. The inner vessel contains the saturated solution of sulphate of copper, with crystals suspended at the upper part to maintain the saturation of the fluid, and its conducting power should be increased as much as possible by the addition of dilute acid. Before we determine what is the best exciting fluid to be used in the iron cell, we must determine what salt of iron is most desirable to be formed during the action of our apparatus. Iron forms soluble salts, with a considerable variety of acids, with muriatic, nitric, and sulphuric &c.; but I am inclined to believe, from my experiments, that the sulphate is the most convenient salt to be generated, therefore, we must employ a solution of some sulphate, of which the sulphate of zinc, sulphate of soda, or what is, perhaps, best, sulphate of magnesia, or Epsom salts. This salt is retailed by chemists for about one penny an ounce, but the electro-metallurgist will find that he will be enabled to buy a pound for about two-pence. I have tried a great

variety of other saline substances in the outer cell, as nitrates, chlorides, but upon the whole, the sulphates appear to be entitled to the preference. The low combining number of iron adds much to its advantage, for twenty-eight grains would be as effective, that is, would generate as much power, as thirty-two grains of zinc. By using an iron positive pole, I feel no doubt that many who have never succeeded in making electro-medallions heretofore, will be enabled to carry on their operations although slowly, yet, with perfect success. A box, divided by a porous diaphragm, and every other single cell apparatus in which we can place a large surface of metal, is suitable for the application of iron as the positive metal. It is really very pretty to pick up a few old rusty nails, and from them generate a sufficiency of the extraordinary and mysterious power of galvanism to make a copy, by a few minutes' labour and a few hours' patience, of the most elaborate work of art that the exalted imagination and the untiring patience of the ancient Grecian could possibly execute. When we can obtain an accurate cast of a Syracusan coin, worth upwards of one hundred pounds, by two or three old rusty nails, and the solution of a penny-piece, let no one henceforward throw away or despise an old rusty nail.*

There are other metals besides zinc and iron that might be used to generate electricity: thus, lead will reduce copper, silver, gold, and various other metals. When it is employed for electro-metallurgical experiments we must form a soluble

* Since writing the above, I perceived the following paragraph in "The Chemist" for this month by Mr. Z. J. Rockline, which I subjoin entire:—"In all my electrotype experiments, I have employed, and with the greatest success, ordinary sheet-iron instead of zinc for the positive metal,—than which it is much cheaper. The difference must, I think, be palpable in large electro-castings, where extensive surfaces of zinc would be necessarily requisite. Iron, in the form of cylindrical rods, which are extensively manufactured, would, if cut into suitable lengths, form most excellent and cheap substitutes for the zinc bars hitherto used in circular constant batteries. To electrotypists, this metal, in whatever form it may be used, must prove a cheap substitute for zinc."

salt, of which the acetate and nitrate are most conspicuous. If we use nitrate of potash in the outer side with the lead, and a solution of metallic salt, say of copper, in the inner side, with the negative plate, the reduction will take place. It is vain to attempt to reduce a sulphate by this salt, for the sulphate of lead is absolutely insoluble. Its equivalent number is very high, one hundred-and-four of lead being equal to thirty-two of zinc, which is one serious objection to its use. The only chance of its ever being employed for the reduction of any metal, especially copper, is the possibility of the nitrate of lead, formed during the galvanic action, being a valuable product, for were this the case we should obtain our power for nothing, and the cost to the electro-metallurgist would be only the value of the weight of metal reduced, plus, the cost of the previous process for converting it into a metallic salt. The sulphate of iron and sulphate of zinc produced in former cases, are now thrown away; but, as in many chemical manufactures the cost depends on the value of the products, it would be desirable for the electro-metallurgist to form a salt which is of value. I throw out this hint for trial, as I have reduced copper from its nitrate, by lead, so if the nitrate of lead could be converted into the carbonate with advantage, we should obtain our power comparatively for nothing; lead gives a feeble electro-motive power, therefore, it requires a large plate, and a thin porous tube.

Tin may be used to generate electricity, it being soluble in muriatic, sulphuric, acetic, oxalic, acids, &c. It has a feeble force, requires a large plate, and thin porous tube. It is best used with dilute sulphuric acid on one side, and the metallic salt, which should be a sulphate, on the other. It reduces several metals, but, unfortunately, has a high combining number, requiring fifty-eight grains to generate as much power as thirty-two grains of zinc. Some alloys of tin and zinc might come into use for the single cell apparatus, did not the high equivalent and price of tin prohibit its adoption.

Other metals might be used, under certain circumstances, as the positive metal to generate power: for instance, copper to reduce palladium, gold, or platinum, silver to reduce gold and platinum; but, as they will probably never be employed by the electro-metallurgist as a positive pole, there can be no occasion to consider them farther: always remembering, however, that whatever metal is employed as the positive element, it is requisite that such an exciting fluid be employed that a soluble salt may be generated during the action of the apparatus, and that sufficiency of water be supplied to dissolve it as soon as formed.

(115.) In all these cases the metals are precipitated at the negative metal of a single battery. In like manner, by whatever other method we can render a plate negative, there will the metal be precipitated; thus, if a battery, sufficient to decompose acidulated water, be connected with two platinum poles, at one pole oxygen, at the other hydrogen will be evolved; therefore at the latter the metal would be precipitated. It has been mentioned before, that one cell of Grove's, two or three of Daniell's, or of my form of battery, will decompose acidulated water between platinum poles; but still, with that series only, a feeble quantity of gas is given off. Now where we wish to employ feeble currents, the series just mentioned may be used with great advantage.

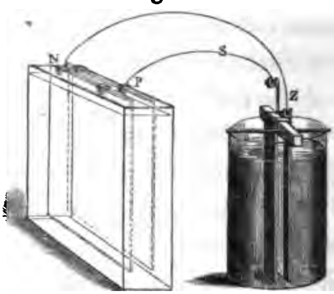
(116.) Where we have considerable resistance to overcome, and require but very feeble quantity, we may use a number of cells, exciting the battery either by simple water, or water acidulated with a single drop of acid in each cell. The oxygen, in this method of reducing the metals, is always evolved at the positive pole, and the acid in combination with the metal set free, so that the solution gradually becomes one acid. In most cases, however, we require to precipitate a large quantity of metal, and then it becomes a matter of importance to effect that object by the smallest series, as by this compound battery apparatus, the cost is multiplied by the number of cells employed.

(117.) For most purposes the last method is very seldom

adopted; but advantage is taken of the affinity which most metals have for the oxygen; and instead of using a platinum pole at the oxygen end of the battery, which affords great resistance to the passage of the galvanic fluid, we employ a piece of metal of the same nature as that which we wish to precipitate, which performs the functions of the positive plate or zincode in the trough. As the solution of metallic salt is continually depositing its metal, the piece which constitutes the positive pole is dissolved by the acid and oxygen which held the reduced metal in solution, and the liquid is thus kept nearly at the same point of saturation. One battery is amply sufficient for this mode, as there is but little resistance to overcome.

(118.) To illustrate this method, let us suppose that we have to take a cast in copper. A solution of a salt of copper is to be placed in a convenient vessel, and the object on which the precipitation is to take place (N), is to be connected with the zinc of the battery (Z), whilst a piece of sheet copper is connected with the silver (S). As soon as action commences, water is decomposed, oxygen passes to the copper pole and oxydizes it, and the hydrogen passes to the negative plate. Whilst the decomposition is taking place, oxide of copper is passing to the negative pole, and the acid to the positive pole; the hydrogen reduces the oxide of copper at the negative plate, whilst the acid combines with oxide of copper at the positive end, and thus the saturation is continued.*

Fig. 12.

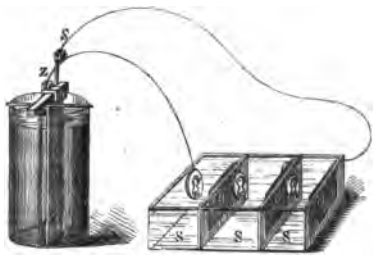


A series of precipitating troughs, arranged like a com-

* It has been mentioned before (99), that Professor Daniell has given a different theoretical explanation of these decompositions, though, practically, the change taking place is the same as here given.

pound battery, may be employed occasionally with only one battery. In this case, we should have one generating cell in the battery, and six, eight, or ten decomposition cells; therefore, by the fundamental laws to which the action

Fig. 13.



of the galvanic fluid is obedient, we should have six, eight, or ten equivalents of metal reduced for one equivalent of zinc. Theoretically, this apparatus exceeds every other in economy—practically, it has not been so much employed as it ought to be, particularly in the reduction of plain copper-plates. The galvanic series is made by alternating the metal to be dissolved (c) with the object to receive the precipitate (*m*), the last mould being joined to the zinc (z) of the battery, and the last copper with the silver (s); the positive plates should be large, and the liquid rendered as conducting as possible to lessen resistance. It is important in this apparatus that every positive and negative plate should possess nearly the same surface, and the solution the same strength, in order that metal of the same quality should be reduced in each cell.

(119.) The apparatus used as a precipitating trough, must vary in shape,—round, flat, square, according to the form of the object to be copied; its dimensions may vary from a single drop to the largest reservoir filled with metallic solution instead of water, and the solution must be altered according to the metal to be thrown down. These will demand a particular description; but here we must say a few words as to the materials best adapted for this vessel, viz. the precipitating trough, and, certainly, glass is preferable in all respects, excepting its brittleness and its expense; these two qualities rendering it much less generally applicable than it would otherwise be. For some metallic solutions it is absolutely necessary to

employ glass, as other vessels are more or less acted upon by them. Porcelain of some kinds, such as Wedgewood's, &c., is found to be nearly equal to glass, though it does not altogether possess its unalterable properties. However, even this is too expensive, and we have recourse sometimes to the common earthenware. Doubtless, many will be astonished, at being informed that most metallic substances will penetrate through the glazing, into the very heart or biscuit of the jar, and freely pass to the exterior of this description of vessel. This may be thoroughly prevented by coating the interior with pitch. The best iron-stone ware is invaluable to the electro-metallurgist; if well glazed they will last for any length of time. A refiner showed me some that he had used for parting gold during twenty years, as good as new. Whenever round vessels can be employed, the electro-metallurgist will be enabled to find them ready-made, at the large earthenware houses, as they are frequently used as salting vessels. If they could be manufactured similar to a trough they would be of universal application; but the makers complain of their warping in the oven. Wooden vessels are more frequently employed than these, because they admit of great variety of form, and can be rendered completely water-tight, by a cement composed of bees' wax one pound, rosin five pounds, red ochre one pound, and two table-spoonfuls of plaster of paris. A common tin trough, or especially a leaden vessel, will answer, but the interior must, in like manner, be coated either with cement or pitch. Leaden vessels are particularly applicable when the metal is to be reduced from its sulphate. One advantage of the pitch is, that the salt in solution has but little tendency to crystallize upon it, which, with other substances, is a very troublesome property; as, occasionally, the whole of the salt from a solution will pass to the outer part of the vessel, thus covering it with crystals. Slate troughs have also been frequently used; they ought always to be painted or pitched, to prevent the absorption of

the liquid, which is apt to penetrate into the slates, and crystallize and disintegrate the substance, which is always made up of numerous layers. The sides are generally bolted together with copper ties; but slate vessels should altogether be discarded, as they are not found to last above a twelvemonth.

Troughs of a peculiar construction have been employed by my friend Mr. Terry; he obtains two boxes, one so much smaller than the other that a space of half an inch is everywhere left when one is inserted in the other. The interval is filled with melted pitch, and the inner one is lined also with the same material. He finds that troughs made in this way are admirably adapted for the intended purpose, and, doubtless, for large vessels they are the best that can be made. I am not aware that they have been employed at present to a large extent, but they bid fair to come into extensive operation.

A galvanic battery and precipitating trough is the process almost universally adopted for all large objects, and there are many reasons why it should be employed. In the first place, we are enabled to regulate the quantity of electricity to the strength of the solution far better than by any other method; secondly, we are enabled to keep up nearly a uniform strength of solution, and, lastly, the process is frequently cheaper. In fact we have two or three manufacturing processes going on at the same time; we are not only generating our electricity and reducing our metal into the form we require it, but we are actually forming, by the same operation, our sulphate of copper or other salts. To reduce metallic copper from crystals of blue vitriol, or silver from lunar caustic may appear to the unlearned to be a sort of alchemical operation, whereby copper or silver is actually made; but this is by no means the case, for we only re-obtain that metal which we had formerly made into the salt, and we have to pay, occasionally, at a most exorbitant rate for that change. All this cost we save by making the battery our manufacturer, and the trough our laboratory, for by using a certain portion of

metallic salt in the first instance, the metal, during the action of the battery, is reduced, and the acid combines with another portion of metal, so that, in this way, the acid contained in a few ounces of metallic salt may be employed over and over again, as there is no limit to the amount of metal that might pass through it.

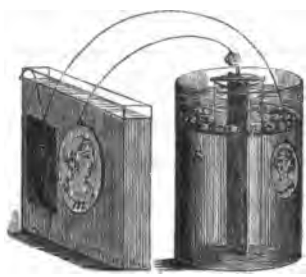
The galvanic battery and precipitating trough need not be joined together like Siamese twins. They may be separated to any distance provided the conducting wires afford no resistance to the passage of the fluid; therefore, when we separate them to any amount we should make our connecting rods of copper, which is a good conductor, and take care to employ thick rods instead of wire. Practically, it is found convenient to have our batteries in one room, and our troughs in the other, as Mr. De la Rue has them. In the first room, everything necessary for the galvanic batteries should be kept, such as zinc, acid, mercury, connecting wires, &c. &c. In the other room, everything should be methodically arranged for the Electro-Metallurgist. If operations were carried on in a very extensive scale, and a great variety of metals were being reduced, then would the manufacturer do well to devote a separate apartment to each separate metal. I can see in my mind's eye a large Electro-Metallurgical manufactory, with the batteries in a room in the centre, surrounded by rooms on every side, in each of which a different metal is being deposited.

(120.) Another form of apparatus may be employed occasionally with advantage; when we require a considerable intensity, or power to overcome obstacles, and do not wish to incur the expense of a large series. It is a union of the single apparatus and the battery. In the decomposition cell we have a porous tube, containing the acid and zinc, and in the outer part we have the solution to be decomposed. The zinc is to be connected with the silver of the battery, and the zinc of the battery with the negative plate in the decomposition cell, and thus the circuit is completed. It is manifest

that this apparatus increases the power, by adding one more to the series, and by using zinc at the positive pole of the decomposition cell but little impediment is offered to the electric current.

(121.) There is yet another mode by which we can precipitate the metals with the utmost cheapness, though the length of time required is very much increased by the process. We use here the Daniell's battery apparatus, or single cell for the reduction of the metal; but instead of connecting the zinc (z) with the negative metal at once, we make that zinc and medal a battery, to be connected to another decomposition cell. In this we have a second medal (*m*) as a negative plate, and a piece of copper (c) as the positive plate. The second medal (*m*) is connected with the zinc of the first cell, and the copper (c) with its medal. In this way, with one pound of zinc we obtain two pounds of copper. The application, however, of the second cell affords an impediment, and, therefore, the porous tube in the first cell should be as thin as possible. This very ingenious apparatus was devised by Mr. Mason, but has not been much used, because it has not been sufficiently known.

Fig. 14.



(122.) The whole management of the precipitation of metals, depends for its success on a right knowledge of the principles of quantity and intensity, or, more correctly speaking, of resistance and electromotive power. The latter property does not influence the result, as we shall hereafter see, so much as the former, but, in most cases, this should be rather abundant than deficient. The intensity, so far as regards electro-metallurgy, may be increased in two ways; by adding to the series, or by using exciting liquids, capable of giving greater intensity, or primitive force to the Galvanic current. The quan-

tity of the current may be increased by enlarging the size of the negative plates of the battery, by increasing the strength of the acid solution, by using a larger anode, zincode, or positive pole in the decomposition cell, by diminishing the distance between this and the negative plate, or, which is by far the best, by using the fluid in the decomposition cell, in that state which most favours the convexion of the current, or, in other words, diminishes the resistance to its passage. Each of these, separately, are quite sufficient to regulate the quantity of electricity passing.

(123.) To ascertain the exact quantity of electricity passing, a galvanometer must be employed, especially for very feeble currents; but, if my form of battery be used, the operator can judge with sufficient accuracy of the quantity of electricity passing, from the evolution of hydrogen from the negative plate. All instruments are incumbrances to the practical mechanic, and I believe that no workman would require anything farther, if my battery be used, than the ocular or aural test which the hydrogen affords.

(124.) The position of the substance upon which the metal is precipitated, causes, in certain cases, a very singular phenomenon in the deposit ; for if it be placed vertically in the apparatus, or especially if the upper part overhang the lower part of the plate, a series of lines will be produced, amounting, in some cases, to grooves of an inch in depth. The cause of this is easily discovered, if the solution be watched whilst the battery is in active operation ; it will then be seen that as the hydrogen reduces the metal from the fluid, it directly becomes colourless, and lighter than the surrounding solution. It, consequently, rises and causes a current, which, like a stream, is reflected in various ways, at every elevation or obstacle. Having once made for itself a channel, it keeps to it, and increases till the lines become of the depth which I have mentioned. This prevents the deposit being of uniform thickness, and makes the plate valueless. It may, how-

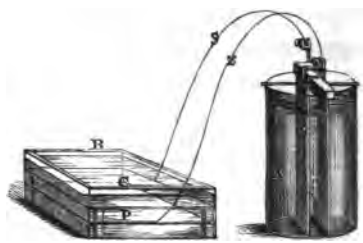
ever, in a great measure, be obviated, by giving the plate a slight inclination, or this tendency may be entirely destroyed by placing it horizontally. If the metallic solution is used stronger, the lighter solution instantly mixes with the denser, and, also, when the deposition is very slow, these lines are not seen.

In conducting our electro-metallurgical experiments, we must recollect that, in every solution of a salt, the heavier parts are apt to subside to the bottom, so that, in reality, at the bottom of the vessel, the solution is saturated, whilst at the top the solution contains but little metallic salt. This property is far more evident when the new salt is formed in the liquid; thus, in every instance, where a metal is being dissolved, it should never be placed at the bottom of the solution, or else the salt will not be able to diffuse itself over the liquid, but will crystallize upon the metallic plate, completely incasing it. On the contrary, if it is placed at the upper part of the solution, the salt newly formed, will be spread more evenly over the fluid, which is a circumstance of great importance for almost all operations. These facts would point out the horizontal decomposition apparatus to be the most philosophical, for in that vessel, the metal removed by decomposition of the salt on the negative plate from the lower part of the solution, has its place immediately supplied with a new portion of salt derived from the action on the positive pole, and thus the fluid next the negative plate is always maintained about the same point of saturation. Practically, however, the horizontal apparatus has some disadvantages which affect its universal application, for in this apparatus the objects to be copied cannot so readily be immersed in the liquid or removed from the trough. If the relative position of the poles be reversed, the positive being placed at the bottom of the vessel, crystals of metallic salt will encase it, and, at last, stop further action, whilst the negative pole will be surrounded with a liquid containing little or no metallic salt, and spongy metal will be

reduced. I rather dwell on these phenomena, having heard that one of the first practical electricians that this country can boast, has, inadvertently, recommended the positive pole to be placed at the bottom, clearly, however, without having tried by experiment the effect of such position.

In conducting the series of experiments for my first edition, which led me to recommend the horizontal apparatus for many purposes, I found that some metals could not actually be reduced without it from an imperfect distribution of the salt. The use of the horizontal apparatus (B), then, by placing the positive pole (C), or metal to be dissolved, above the negative, or pole to receive the deposit (P), is only to afford this equable distribution, and, therefore, is to be superseded whenever we can effect that object more readily. The solution must be filtered occasionally when this apparatus is employed, to separate any particle of dust, and the positive pole must be kept very clean. I enter more fully into these facts, because the apparatus has been recommended by Authors without their seeming exactly to understand for what direct object it is required.

Fig. 15.



Mr. De la Rue, for the purpose of keeping up the same strength in his metallic solution, fixed up an extensive apparatus for ensuring that object by the circulation of fluid. He fixed a large tank at the upper part of the room, and another at the bottom. The upper one was filled with the metallic solution, and was suffered to run through the troughs to the lower vessel, from whence it was again pumped up to the higher. Now this appeared to be the most direct and philosophical manner of overcoming the imperfect diffusion of the salt, but it caused on the negative metal such curious circular lines, and the process of the deposition of the metal was so much

interfered with, that the apparatus was obliged to be abandoned. This experiment is extremely interesting, as showing that an idea most excellent and philosophical in principle, may fail in its application, through the interference of some new influential circumstance, which it would be impossible to foresee.

(125.) The new deposit of metal may, sometimes, be removed with the greatest facility, at others, it adheres with such firmness as to form one metallic mass, with its mould, from which it cannot be separated by any means whatever. Now we require both these properties for different purposes, and though, heretofore, the results have been too much the effect of chance, doubtless it is a matter of the greatest consequence to have such a control over the process, as to obtain, with certainty, either, as we may happen to require them.

(126.) The adhesion of the original and duplicate is termed, technically, *buttoning down;* the non-adhesion has not been, as yet, vulgarly christened. Both depend on two facts, the enfilming of metals by air, and the possibility of that becoming a pole. (35.) These properties have been fully entered into in the first book, but here we have to notice their practical application. If a piece of smooth metal be plunged into water, it will resist wetting, and in that state is to be used, when we do not wish the deposit to adhere to its mould. In order to take advantage of this property, the plate is to be dipped into the solution, and the circuit immediately completed. The air would now appear to be the pole, and to afford a separation between the original and duplicate. Of course the plate should be neither heated nor rubbed with potash or nitric acid, previously to its submersion; and, above all, should not remain in an acid solution for a single moment before the galvanic circuit is completed. Sometimes one or more of these circumstances will take place partially, and then a partial adhesion or buttoning will ensue. After any plate has been soldered, it should be allowed to remain in a

cold place for at least twenty-four hours, it will then regain its film of air.

The metals are not singular in their affinity for air, nearly every substance in contact with it becomes coated with it. Paper, although having a strong affinity for water, has also a similar affinity for air. Thus, when large quantities have to be damped for printing, the air becomes a serious obstacle. By the machinery introduced into the Bank of England, as well as in the Bank of Ireland, by the late Mr. Oldham, the paper on which Bank notes are printed is placed in a vessel connected with an air-pump, and the air is pumped out, which causes a vacuum. Into this water rises, and a million of notes, if necessary, are in a very few minutes wetted thoroughly. It is usual to pass the paper through rollers to deprive it of excess of fluid, and thus, by a simple application of a chemical fact, a saving of much labour is effected. The same principle is brought into operation in the process of Kyanizing timber, where the air is first pumped from the wood, and then a solution of corrosive sublimate rushes into the pores of its structure as soon as air is again admitted.

The non-adhesion of metals is not, in all cases, dependent on the adhesion of air; sometimes a film of oxide, at other times a thin film of sulphuret, or a thin film of grease will prevent this property. I have at this moment before me a wire, the reduced metal covering which is in several distinct layers, caused by simply withdrawing it as many times from the solution, and allowing it to dry before it was again immersed. Reduced copper plates will, occasionally, have this imperfection, being in a series of layers from a similar cause.

(127.) When we are desirous to employ the opposite property, or to cause the new deposit to adhere, we pursue a contrary course; we either heat the metal and plunge it into water, or rub it with a solution of caustic potash, with nitric acid, or else we make it the positive pole of the battery,

and in that state place it in the solution: for then the surface, being quite clean, allows the deposit to take place on the metal itself, and not on the pole of air. It will then adhere so firmly, that no mechanical separation can be effected, as some can testify, who, ignorant of these facts, have entrusted valuable copper-plates in acid solutions, and entombed their device in a mass of copper, from which it could never be disinterred.

The observations on the enfilming of the metals, after having been exposed to the air for a short period, applies to many cases besides electro-metallurgy. The application of heat to the Daguerreotype plate, before it is exposed to the vapour of iodine, is, perhaps, on the same principle, and doubtless any of the other modes which I have described for cleaning the plate, will answer as well.

(128.) The adhesion, or buttoning of one metallic plate to another, must not be confounded with apparent adhesions of the duplicate to the original, arising from the copper growing round the edge, and firmly embracing it. This is to be remedied in a great measure, in the first instance, by coating the edge with a layer of lac varnish or grease, which prevents the deposit taking place at that part. After a considerable lapse of time, the plate increases laterally, and covers the coating.

(129.) The lateral growth of a plate is a property of considerable importance, for if a particle of non-conducting substance be placed upon a metal, it will be covered. This lateral growth, or the diffusion of electricity over a large surface, differs with every metal, nay with every salt of the same metal. In this way, drawings made on copper, with varnishes, may be multiplied. If a non-conducting substance is to be copied, by means of a thin film of conducting substance, a break in the continuity of the latter will not prevent the formation of a perfect plate. For the same reasons, care must be taken that no air or gas-bubbles adhere to the

plate, for, in like manner, they will be enfilmed, and leave a little flaw or gap in the duplicate plate. To cast metals upon an air bubble, seems, at first, too wonderful to be believed, and, in former times, would, doubtless, have subjected the discoverer to destruction, on the supposition that he was in communication with an evil spirit; but, in these latter days, we find that it is even more difficult to prevent than to effect.

He who desires to make electro-metallurgy his business, must well consider the relative expense of the materials absolutely essential to his processes. An undue attention to this very important consideration has caused experimenters to take out patents and incur great expense, for modes of working in metals by the voltaic fluid, when the object could be obtained in the ordinary mode of proceeding, at one half the trouble, one half the cost, one-sixth the time, and, even then, nearly as well as by the galvanic current. To estimate the expense of working in metals by the voltaic fluid, we may divide the processes into several departments. The single cell, the battery, the compound battery apparatus, in which manufactured zinc is employed; the odds and ends' battery which is applicable to raw zinc; the compound decomposition apparatus; Mason's apparatus; iron single cell apparatus; tin single cell apparatus, &c.

An equivalent of power (87) may be obtained in the single cell, by the solution of 32 grains of zinc; now as 7000 grains of that material in a manufactured state, that is, rolled, are worth nearly 7*d.*, the equivalent of zinc in round numbers would cost $\frac{1}{34}$ of a penny. To this must be added waste of zinc not used, destruction of porous tubes and cost of saline excitant which would probably bring the charge up to the $\frac{1}{20}$ of a penny.

In the single battery, provided it be of my construction, the equivalent of power would cost about the same or rather less. In this case it would be the zinc (the same as in the single

cell) the acid waste of zinc from local action, and the difference of value between the manufactured zinc and the remnants that necessarily occur, (52) say $\frac{1}{20}$ of a penny. If the constant battery were employed, the cost would be raised from one and a half to twice that sum, making allowance for the value of the copper reduced. The application of the nitric acid batteries for electro-metallurgy, would entail more than treble this cost, raising the sum to $\frac{1}{7}$ of a penny for the same equivalent of power. The expense of the power derived from a compound battery would be the same as that of the single battery $\frac{1}{20}$ of a penny, multiplied by the number of cells, so that if twenty cells were employed, the equivalent would cost ($\frac{1}{20} \times 20$) 1*d.*

By the use of spelter in the odds and ends' battery, we lower the price to nearly one-half or the $\frac{1}{40}$, because spelter is much cheaper than rolled zinc, on account of the difficulty of rolling, and because there is but little local action, and no remnant of undissolved metal to cause waste.

The compound decomposition apparatus is the reverse of the compound battery apparatus, for the equivalent of power, as obtained from a single battery, must be divided by the number of decomposition troughs: thus if we have twenty cells it would cost($\frac{1}{20} \div 20$) $\frac{1}{400}$ of a penny for each trough.

Iron to give an equivalent of power, must lose 28 grains, that being its equivalent; therefore, as 7000 grains in the manufactured state are worth from 1*d.* to 2*d.* it would cost about $\frac{1}{75}$ of a penny, making allowance for waste and exciting fluid.

The equivalent of power, if obtained by the agency of tin, of which 58 grains would be dissolved, costs, making allowance for waste, exciting fluid, &c., $\frac{1}{10}$ of a penny, reckoning tin at 9*d.* a pound.

From the above considerations, we form the following table of the bare cost of the materials to produce an equivalent of galvanic power, under different circumstances: it is assumed

that the salt of zinc, of iron, or of tin, is of no value:—

Zinc Single Cell .	$\frac{1}{20}$	of a penny.
Iron Single Cell .	$\frac{1}{75}$	„
Tin Single Cell .	$\frac{1}{10}$	„
Battery . . .	$\frac{1}{20}$	„
Constant Battery .	$\frac{1}{10}$	„
Grove's Battery .	$\frac{1}{7}$	„
Odds and Ends' Battery	$\frac{1}{40}$	„
Compound Battery .	$\frac{1}{20}$	$\times$ by the number of cells.
Compound Trough .	$\frac{1}{20}$	$\div$ by the number of troughs.

Having obtained this table, an important clue to the expense is arrived at, for if we are desirous of ascertaining the cost of the reduction of a metal from its particular salt, we ascertain its equivalent number (87), then the value of that quantity, and lastly, by adding this cost to that of the power, we arrive at the bare value of materials for that equivalent. Having ascertained the value of the number of grains corresponding to the equivalent number of a single proportion, we learn the cost of 7000 grains or one pound avoirdupois.

Let us suppose, for instance, that we are anxious to know the cost of the reduction of copper from its sulphate, we find that the equivalent of this salt is 125, which at 4*d.* for 7000 grains, or one pound, would amount to 7000 : 4 : : 125 : $\frac{1}{14}$ of a penny. This we add to the number appended to the particular process against the above table, which would make the cost for one equivalent of copper, or 32 grains, as reduced by the single cell, nearly $\frac{1}{8}$ of a penny, $\frac{1}{14} + \frac{1}{20} = \frac{1}{8}$ of a penny. Then to ascertain the cost per pound, as 32 the equivalent of copper : $\frac{1}{8}$ of a penny : : 7000 = to about 2*s.* 3*d.* a pound. On the negative side, we have in addition, a certain waste of materials there is more metal reduced upon the edges than we require, and some copper left in the exhausted solution, of which it is impossible to give exact estimates.

So much for the cost of the materials in a single cell, and to put them in the form of an equation, C, the cost = (e) value

of an equivalent of power + (s) the cost of an equivalent of metallic salt—

$$C = e + s.$$

To ascertain the cost of our materials in a battery apparatus, the equation would be altered, C, the cost = e, value of equivalent of power + m, the price of an equivalent of rolled metal suitable for our positive pole. To this we must add a loss for the impurities in the metal, the loss from remnants, and the occasional cost of a renewal of the metallic solution.

$$C = e + m.$$

Let us take an example of the precipitation of copper from the single battery apparatus. $C = e\ \frac{1}{20}d. + m$, with a little loss $\frac{1}{18}$ = about $\frac{1}{9}$, for thirty-two grains of metal reduced. In this case, rolled copper is estimated to be worth one shilling per pound.

Although every person ought to make the calculation for himself, before he enters into any large operation, I subjoin, as a rough guide for the electro-metallurgist, another table, showing the price of the reduction of copper from its sulphate by each of the methods detailed above :—

		per equivalent.	*s.*	*d.*	
Single cell	zinc	$\frac{1}{8}$*d.*	2	3	per lb.
	iron	$\frac{1}{12}$*d.*	1	6	
	tin, nearly	$\frac{1}{6}$*d.*	3	0	
Single battery		$\frac{1}{8}$*d.*	2	3	
Daniell's		$\frac{1}{6}$*d.*	3	0	
Grove's		$\frac{1}{5}$*d.*	3	7	
Odds and ends'		$\frac{1}{10}$*d.*	1	0	
Ten cell compound battery		$\frac{4}{7}$*d.*	10	5	
Ten cell compound trough		$\frac{1}{13}$*d.*	1	5	
Mason's plan	1st. cell	$\frac{1}{8}$*d.*	2	3	
	2d. cell	$\frac{1}{14}$*d.*	1	3	

Besides the elementary cost, we have to pay for the negative metal, or moulds on which our metal is reduced, we have the time requisite to keep the apparatus in action, we have the rent of the room in which the operations are conducted, and a hundred other circumstances, for which no general

computation could possibly be given, as they vary with every case. All these things will be considered in the description of the processes. The preceding equations show clearly that electro-metallurgy shines conspicuously forth for utility, where the value of the metal is great and its equivalent high; thus, by applying our equations to gold, we find that the equivalent of power is nothing compared with the value of the metal, for we reduce two hundred grains of gold for $\frac{1}{20}$ of a penny, whilst the metal is worth nearly 2*l*. For this same cost of $\frac{1}{20}$ of a penny we can obtain only thirty-two grains of copper, that being its equivalent; but if we desire to make hydrogen, we can only get one grain for our money. This simple principle prevents the employment of the galvanic power for the production of gas for illuminating purposes, as, if we make our calculations, we shall find that the cost of materials for this purpose would be about £7. 10*s*. per 1,000 cubic feet, whilst the gas-companies supply us at nine shillings for the same quantity. Had the equivalent of hydrogen been 200, the cost of its production would have been only ninepence, which would have been the means of converting every coal-gas company in the country, into a galvanic-gas company, and with the gas, such an abundant supply of galvanic power would have been available for electro-metallurgy, that all other modes of working many metals would have been entirely superseded.

CHAPTER II.

ON SUBSTANCES CAPABLE OF RECEIVING THE METALLIC DEPOSIT.

Substances on which the deposit may take place, 130—131. Metals, 132—136. Non-conducting substances; Sealing Wax, White Wax, 136—139. Absorbent substances, as Paper and Plaster of Paris, 139—141. Means of rendering them non-absorbent, 141—142. Means of copying non-conducting substances by metals, by plumbago, 143—145. Comparison between the methods, 145.

(130.) The voltaic deposit of metal may take place upon any conducting substance, which is capable of acting the part of the negative metal, in the arrangement. The laws which relate to this, are the same which regulate, in a similar manner, the plates of the battery. The deposit may be effected upon most metals, except the earthy and alkaline, and upon any alloy or compound of them. It may, likewise, take place upon charcoal and plumbago. When the metals are employed, the effect is evident enough, for the arrangement differs in nothing from that of a Daniell's battery.

(131.) Where we desire the duplicate to possess a surface and form exactly like those of the original, it is of the utmost importance that the metal on which the deposit is to take place, should not of itself decompose the fluid, because, in that case, the duplicate is sure to be more or less impaired. To illustrate this, zinc, lead, tin, or iron, in sulphate of copper, precipitate the copper immediately from its solution, but the former metals are dissolved exactly in equivalent proportion with the reduction of the latter. The solution of this metal impairs the surface, and renders the duplicate less perfect. This may be prevented, in a great measure, by taking care

that the voltaic current is passing at the moment when the metal is plunged into the fluid; and this mode of proceeding is supposed, by many, entirely to supersede the elective affinity, as it is termed, or the spontaneous action of the metal on the fluid. But I can decidedly affirm, that no battery of large series will entirely prevent the solution of the more oxidizable, and the reduction of the less oxidizable metals, because it is impossible to protect by a negative tendency a metal where the hydrogen is in a condition to be absorbed.

The metals which can be employed with advantage to receive a deposit of any other metal, are, therefore, those which are not acted upon by the particular fluid in which they are immersed; those, however, which are but slightly acted upon, may still, in some cases, be employed. The same thing may be said of the non-metallic bodies when coated with a thin film of conducting substance, for it is essential, in order to make an accurate cast of any body, that it should not be decomposed by the fluid in which it is inserted, but remain entire during the time requisite for its immersion. The following is a short list of substances which may be used to receive the deposit of metal:—

Carbon . .	In all metallic solutions, acid, neutral, or alkaline.	
Platinum . .	In all metallic solutions, ditto	ditto
Gold . .	Ditto	ditto
Palladium . .	Ditto	ditto
Silver . .	In all alkaline, in all but the preceding, saline and acid.	
Copper . .	Ditto	
Lead . .	Ditto	ditto
Bismuth . .	Ditto	ditto
Antimony . .	Ditto	ditto
Tin . .	Ditto	ditto
Iron . .	Ditto	ditto
Zinc . .	In some alkaline	ditto

NON-METALLIC SUBSTANCES.

Sealing-wax .	In all saline or acid solutions; not in alkaline.	
White wax .	Ditto	ditto
Bees' wax and rosin .	Ditto	ditto

Stearine . .	In all saline or acid solutions ;	not in alkaline.
Spermaceti .	Ditto	ditto
Plaster of Paris, prepared . .	Ditto	ditto
Some animal substances	Ditto	ditto
Most vegetable substances . .	Ditto	ditto

Now by the preceding table we perceive that some substances may be immersed in one solution with impunity, while others would be destroyed by its action on them. It is, therefore, important to know, when we have a substance which is acted upon by any metallic solution, how to make a reverse from it that shall not be injured. For convenience a table is appended, showing at one view the modes of preparing moulds of different substances. The perpendicular row is a list of the objects to be copied, the horizontal the means of multiplying them. Suppose the operator had a valuable silver medal, of which he was desirous of making a fac-simile, he would look in the table against silver, and would there find that he could make a mould, or reverse, in copper, by electro-metallurgy; but to this he would doubtless object. He would then see by what other methods he could also make a mould, and he would find that he could succeed with each of the processes given, and perhaps he would prefer plaster of Paris, as least likely to be injurious to his medal. Having made the mould in plaster, he would see from the former table, that when prepared it might be placed in any saline, or acid solution of copper, to form the fac-simile.

LIST OF THE PRINCIPAL MODES OF MAKING MOULDS OR REVERSES OF VARIOUS OBJECTS.

METALS.	COPPER.	LEAD.	ALLOYS OF LEAD.	SEALING-WAX.	STEARINE, SPERMACETI, WAX AND COMPOUNDS.	SULPHUR.	PLASTER OF PARIS.
Copper	by Electro-Metallurgy.	by percussion, rolling.	by clichée.	by fusion.	by fusion.	by fusion.	by mixture with water.
Silver	d°	d°	d°	d°	d°	d°	d°
Gold	d°	d°	d°	d°	d°	d°	d°
Platinum	d°	d°	d°	d°	d°	d°	d°
Lead	d°	..	d°	d°	d°	..	d°
Alloys of	d°	..	by clichée.	d°	d°	..	d°
Tin	d°	..	..	d°	d°	..	d°
Iron	d° by Percussion.	by percussion, rolling.	by clichée.	d°	d°	by fusion.	d°
Other Metals	by Electro-Metallurgy.	..	..	d°	d°	..	d°
Sealing Wax	d°	by percussion.	.	..	d°	..	d°
Bees' Wax and Compounds	d°	..	..	..	..	..	d°
Stearine	d°	..	..	..	..	..	d°
Spermaceti	d°	..	..	..	..	..	d°
Sulphur	..	..	by clichée.	..	by fusion.	by fusion.	d°
Bread-crumbs	..	..	..	by fusion.	..	..	d°
Plaster of Paris	by Electro-Metallurgy.	..	by clichée.	..	by fusion.	by fusion.	d°
Glue and Whitening	not.	..	d°	..	d°	..	d°
Animal Substance	by Electro-Metallurgy.	..	some by clichee.	some by fusion.	d°	by fusion.	d°
Vegetable Substance	d°	..	d°	d°	d°	by fusion.	d°
Gum	..	..	..	..	..	..	d°
Isinglass	..	..	..	..	..	..	d°
Siliceous Bodies as Glass	by Electro-Metallurgy.	..	by clichée.	by fusion.	by fusion.	by fusion.	d°
Aluminous d°	d°	..	d°	by fusion.	d°	d°	d°

(132.) Carbon, from its cheapness, from its indestructible nature, and from its being unaltered in all metallic solutions, is invaluable for electro-metallurgy. One variety of it, graphite, or plumbago, usually called black-lead, has a most extensive application, which we shall hereafter have occasion more especially to describe.

Platinum, from its being unaltered by any solution, holds an important place for the reception of every metal; its great price, however, must always be an impediment to its general use.

(133.) Gold is equally valuable with platinum, but is still more expensive; yet when extended to that state in which it exists as gold-leaf, it may be applied over the surface of any soft substance, and thus a metallic surface is presented. This plan may be employed with other metals, such as silver or tin; but we have other methods which render all these modes unnecessary.

(134.) Silver only reduces gold, platinum, palladium, and two or three more metals from these acid solutions, and therefore, may be employed as a negative one for the reduction of metals. Silver-leaf of a thickness of about one square foot to the ounce, and made of pure metal, is much used by the forgers. The process they adopt is, to place the coin to be copied on a piece of wood, and upon the coin they place a piece of this thin silver. They beat it gently with a wooden mallet, till a perfect impression is taken on the metal, a result soon obtained. They then copy the opposite side of the coin in the same way. The two impressions are then soldered together, and the manufacturer sallies forth and risks his neck for the illicit shilling which has cost him this labour. The reader will doubtless have no inclination to practice this fraud, and, therefore, it is unnecessary to enter farther into the process; but it should be borne in mind, that the same means may be employed with a better intention by the electro-metallurgist, to obtain a mould.

Copper may be used for the reception of many metals, but unless the object to be coppered happens to be a mould, we cannot easily make a reverse in this metal, except by electro-metallurgy.

(135.) We have now to treat of the alloys of lead, tin, bismuth, antimony, and zinc, which demand especial attention, because there are means of casting these alloys, and of making reverses, moulds, and medals, by more ready methods than we possess for any other metals. It has been remarked that these alloys have melting properties, not only below the mean of the melting points of the respective metals which compose them, but even some of them considerably below the fusing point of the most fusible metal that enters into their composition. To some of these alloys we owe the manufacture of type, to others the process of stereotyping, to others that of polytyping or clichée. The composition of the type-metal is stated to be 1 part of lead to 16 of antimony, and sometimes a portion of copper is added; this proportion probably varies at each foundry; as they generally consider that part of the business a secret. Other compositions are given as 6 to 2, 4 to 5, or 4 to 1 of antimony to lead. In the foundry there are a number of crucibles, each heated by a charcoal fire, one being allowed to each workman. To make a type, the operator takes a little of the melted alloy in a small ladle each time, and pours it into the mould which has the counterpart of the letter he wishes to make. The moment it is in the mould, he carries it suddenly upwards with a jerk, above his head, by which means the metal is forced into all the fine parts of the work, and a good impression is insured. Now we might expect that those who day by day work at this occupation, would attain to certainty in their proceedings; but this is by no means found to be the case, for they form a very large number of imperfect types which are obliged to be re-melted. I give this process to show that with those about

to be detailed a strong analogy to coining is presented. In the first case, it is with a fluid, or semi-fluid, metal; in the last with a solid mass. The alloys which may be used for these purposes are very various, according to the object from which we desire to obtain a reverse, for as a great latitude is allowed in the fusing point, so at one time we prefer the more fusible, at another that which melts at a higher temperature.

The following is a list of alloys which are employed by various authors, to which should be added all the compositions of type-metal, last described, and as antimony possesses the property of expanding in the act of cooling its alloys are well adapted for casting.

	Tin.	Lead.	Bismuth.	Zinc.	
1	4	1	0	0	
2	5	10	1	0	
3	0	1	1	0	
4	1	1	0	0	
5	3	5	8	0	fuses about 212° Faht.
6	1	1	2	0	said to fuse at Faht. 200.
7	1	2	3	0	ditto 200.
8	1	0	1	1	ditto 200.

The alloy No. 5 is called the fusible metal of Sir Isaac Newton. No. 6 is the fusible alloy of Rose. The two last are after the French. Sometimes a little mercury is added by the instrument-makers to render the alloy more fusible, but this ought always to be discarded in electro-metallurgy.

All these compounds are used at a point between the fluid and the solid state, for at that heat they assume a pasty appearance, which is probably caused by the alloy consisting of two parts, one more fusible than the other. In fact, if we examine the mass very attentively, it appears to be composed of a quantity of perfectly solid metal in a fine state of division suspended in another portion of alloy perfectly fluid. Having obtained our alloy in this state, it is ready for the process of making our reverse, and this process is termed the clichée. The alloy marked 1, 2, 3, 4, as well as the compositions for type-metal, will answer for iron, brass, copper, or

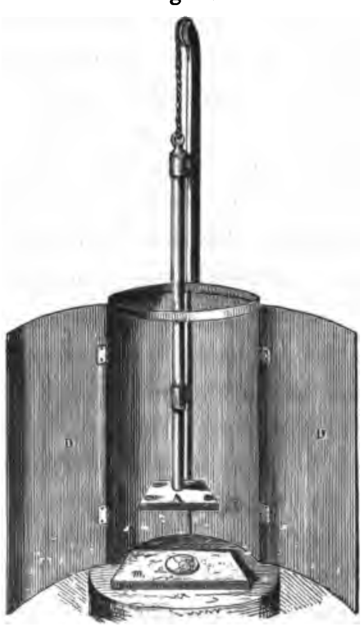
other hard substances; perhaps No. 2 and No. 3 will be found, after type-metal, entitled to the preference. When we desire to clichée from wood, sulphur, or from another clichée, we must employ those alloys which fuse more readily, and Nos. 5, 6, 7, and 8 come into use. If hard metals are used from which to clichée, we should take care to clean them thoroughly before using, and always employ them in a cool state. In using one clichée for making a second we must take care to employ a less fusible alloy for the first than for the second, thus the type-metal and Nos. 1, 2, 3, 4, answer as a primary mould to make casts in 5, 6, 7, 8. To clichée from Plaster of Paris, the material must be prepared either by linseed oil, gum, or gelatine, which processes will be described when treating of those substances, and sulphur moulds must be employed within a few hours of their manufacture.

The simplest mode of making a clichée is to pour a little of the fused alloy on any flat surface, then to skim it clear with the edge of a card that the surface may be most perfectly bright, after which we should wait till it is nearly at the point of cooling, when with a considerable jerk the matrix is to be brought down upon the alloy, by which operation the fluid part will be forced out in all directions, and a reverse equal in polish, sharpness, and beauty to the original will be instantly obtained. If the alloy is used too hot, the surface is apt to present a crystalline appearance; it is therefore, very important that the object should be cool enough to make the alloy perfectly hard, as soon as the blow has driven the metal into all the finest lines. When taking a clichée from an intaglio the air has not always time to get away, in which case little holes or bubbles are very apt to be caused. The surplus metal round the edges of the mould so formed is then trimmed off in a lathe, but this operation is generally unnecessary for electro-metallurgy.

The Italians have a method of taking very perfect moulds with these alloys. They take a portion of the melted mass, and place it on a piece of paper; upon this they lay the

medal, and under both a piece of carpet; upon the medal they place a log of wood, and then a sharp blow on the wood will ensure the sharpness of the cast. The worth of a cast thus made, is from sixpence to half-a-crown. I have before mentioned, the clichée is nothing but a process of coining, and sometimes a sort of coining press is used for these purposes; the medal or other object is fixed either by mastic or by screws on a piece of metal (A), which descends with force on the semifluid alloy. Previously to the operation of striking, the object is suspended by a cord passing through a ring, and attached to the rod of iron connected with the piece of metal (A). When everything is ready, the doors are shut and the cord let loose, which allows the object to fall with great force on the metal.

Fig. 16.



An impression may be given to a perfectly clean bright surface of sheet lead, by placing upon it the object to be copied, and then with a steady hand dealing a heavy blow. By this mode even a sealing-wax impression may be copied, although this, at first sight, would appear hardly credible. By pressure alone, it would be difficult to obtain the result which can be given by the blow. Rolled lead, first scraped, in order to remove any oxide from the surface, and then flattened by running it through a press upon a polished iron plate, will readily take the impression of the most delicate work or engraving. The object to be copied is simply to be placed upon the lead, and then the two are to be sent once, and once only, through the printing-press, as in the ordinary operation for

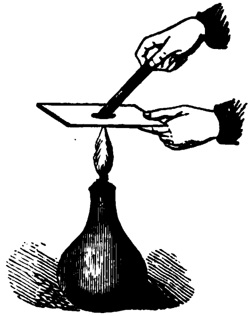
taking a print. The pressure in rolling is far greater than can be given by direct pressure, though there are instruments used by embossers capable of exerting great power. The disadvantage of forming moulds by rolling is a liability of distortion of the image from imperfect stretching of the metal.

The stereotype is not of much value for electro-metallurgy; moulds made of stereotype metal may, however, be employed should there appear to be any occasion to use them. Stereotype-casts are only made practically from plaster of Paris reverses: thus to stereotype this page a plaster-cast would be taken of the type when set up, and this would then be thoroughly baked in an oven to expel all moisture. The plaster-mould is next placed face downwards in a box, and confined in that situation by a plate of iron, when the whole apparatus is lowered into a caldron of melted alloy kept over a fire. It is suffered to remain in that situation a few moments, when it is withdrawn, and the vacuity caused by the contraction of the metal during the process of cooling is supplied by the workman.

(136.) Non-conducting substances are of three kinds; substances having no affinity either for the metal or the solution; substances acted upon by the solution; and, lastly, substances capable of combining with the metal thrown down. Those of the first class are by far the most valuable, but are not very numerous. The best of these is sealing-wax—a composition of shell-lac, Venice turpentine, and colouring matter. Dr. Ure gives, as the proportion in which these are used, four, one, and three. The manufacturers have several varieties, the most expensive of which is the best for making seals. Some of them are extremely hard, as for example, a black wax which is used for filling up the letters in the engraved plates of shop-windows, but I do not know how a difference of composition can affect the properties of the wax in this important manner. The use of sealing-wax is attended with considerable expense, as good wax cannot be

purchased under three and sixpence or four shillings a pound, but it takes impressions of objects of the greatest delicacy with the utmost accuracy. Every one uses this substance, and sealing is one of those operations in which every one thinks that he excels his neighbour in the manner in which he performs it; but, however well satisfied he may be with his skill in the small way, yet the management of large seals is attended with great difficulty and uncertainty. Proof-seals are made by engravers, by holding a piece of card over a flame, and rubbing, gradually, a stick of wax, previously softened by heat, upon the heated card, till a sufficiency is obtained, when the coin is to be pressed upon it. Very large seals are made by taking a good-sized stick of wax, and holding it in a flame, not only till the point, but even three or four inches of its length are lighted. It is then to be held over a piece of paper or card, when large drops of melted wax will keep falling, and in a short period a considerable quantity will be melted. The flame of the stick is to be blown out, and the fluid mass well stirred round and round, till all the air-bubbles are dispersed, and a clear surface of semi-fluid wax is exposed. It is now ready to receive the impression of the object of which we are desirous of obtaining a copy. This is to be laid upon the wax, and pressed with considerable force, and lastly plunged into cold water, so as to cool it suddenly. Much less difficulty attends the use of a metallic die, for that abstracts the heat, and does not adhere. The accuracy with which sealing-wax takes impressions with care, is shown by its copying the lines on mother-of-pearl, and analogous substances, which naturally possess the property of decomposing the rays of light, and the same colours which exist in the original are also to be observed in the copy.

Fig. 17.

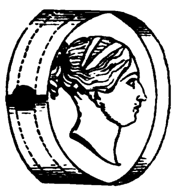


When we are desirous to obtain an impression in wax

from wood or similar substances, they should be previously brushed over with a little salad oil. In these cases, by plunging the wax into cold water, its surface is apt to sink in places, and thus becomes uneven. Very large seals have been made of sealing-wax, by means of placing the mould on the semi-fluid composition, and subjecting it to hydrostatic pressure. In this way the late Mr. Bate succeeded in making perfect seals of four or more inches in diameter.

(137.) White wax may be used for taking casts, and can be procured with least expense by buying the waste ends of wax candles, which may be readily melted over a lamp. The object to be copied is to be very lightly oiled with a hog's-bristle brush previously dipped in that fluid. A moment's exposure of the medal to a current of steam, or even to the breath, will answer the same purpose, because a film of water, for which wax has no affinity, covers the medal, and, therefore, causes a separation between the wax and the metal. A narrow strip of paper should then be procured which is to be wound round the object to be copied, and kept in its position by a piece of twine tied around it. The ends of the paper may be even still better kept together by a little bit of melted sealing-wax. If the object to be moulded happens to be a medal, this is easily accomplished, and in other cases the same thing may be with but little more difficulty effected. By this proceeding we form a kind of rim to the medal. The fluid wax is then to be poured into the cup thus formed, care being taken that no bubbles of air adhere to the medal. The heat at which the melted wax is used influences the success of our operation. If the object to be copied be small, it need not be so warm as if it were of considerable size. The conducting power of the body requires a similar regulation of temperature, for if it be a good conductor, a metal for instance, it has the power of abstracting the heat from the melted wax so rapidly that a higher tem-

Fig. 18.



perature must be employed. As a general rule, the surface of the object should be entirely covered with fluid wax a second or two before hardening commences at any one point, and in the same way the wax should not be so warm as to remain long before it begins to set firm. It is then suffered to remain not only until it becomes solid, but even quite cold, which will not take place in less time than two or three hours, on account of the wax being a bad conductor of heat. It may then be taken off by gently pulling the wax-cast from the medal.

Plaster-casts may be even copied in wax, by simply oiling the plaster with a little sweet oil, previously to pouring in the fluid, and thus a perfectly sharp reverse of the plaster will be obtained. A still better method of taking a reverse from plaster, is to let it absorb as much hot water as it will take up without any remaining on the surface. For this purpose the cast is placed in water not above half its height, and as the water penetrates by capillary action, the surface begins to assume round the edge a slightly dark colour, and the eye can accurately trace its progress till the action is finished. It is then to be enclosed in paper, and melted wax poured upon it whilst it is warm; after which the whole is to be allowed to cool, when the wax will separate from the plaster with the greatest facility. In this process much of the success of our labour depends on the quantity of water employed, a very nice adaptation of that being requisite. If there is too much water it will then be drawn up between the wax and the plaster, after the former has been poured upon the cast, and a wavy hollow surface will be given to the mould which completely unfits it for electro-metallurgy. If too little water be used the wax will penetrate into the pores of the plaster of Paris and adhere to it. The plaster must not be soaked in water one minute longer than necessary, for that will soften the structure, and render the surface infinitely more liable to tear up and be destroyed upon the separation of the wax reverse. Should the slightest adhesion exist, it shows that

the plaster has not absorbed sufficient water, a circumstance which the operator must avoid another time; if, however, a very slight adhesion should exist, it may, generally, be overcome by soaking the mould and cast for a few minutes in water, when frequently a spontaneous separation will ensue. Those engaged in making moulds do not esteem wax as the best substance for taking casts, and, perhaps, with justice, from the reverses made by this substance not entirely possessing the sharpness of the original, the edges of the sharp parts frequently being rounded and dull.

The substance called stearine makes, also, excellent moulds, for which purpose, I believe, it has been much used by Jacobi. Stearine is made from common tallow, by pressing it with an hydraulic machine and squeezing out the fluid parts. This process is, however, imperfect, a portion of the oily matter being always left. The metallic-wick candles are said to be an example of this mode of proceeding. A far better operation of preparing this substance is to saponify the tallow by potash, soda, or, what is more used, lime, and then decompose the soap thus formed with dilute sulphuric acid. In this way excellent stearine candles are made, which, in illuminating powers and cleanliness, are inferior to none. The observations applied to wax are suitable also to stearine, the proceeding in both cases being alike. The price of raw stearine in London, at the present time, is about one shilling a pound. Spermaceti is perfectly analogous to stearine in its properties. It is the solid part of the oil of certain whales, particularly of the *physeter macrocephalus*, or sperm whale; the best is to be obtained from the head of the animal. It is to be used in the same manner as wax and stearine.

(138.) A mixture of equal parts of bees'-wax and rosin may be employed for taking casts, and may be used in a similar manner to wax; sometimes they add a little turpentine, and increase the quantity of rosin. This composition is used a great deal by the Italians, but care must be taken not

to use the fused mixture too hot. The composition should be melted, and then allowed to remain till the bubbles have dispersed, and till it becomes nearly as thick as treacle, when it is to be poured over the object, in the same way as wax.

(139.) Of the second kind of non-conducting substances, there are several varieties: paper, plaster of Paris, &c., which are acted upon by the fluid. Paper is of no great value for obtaining a reverse from any object; by the embossing machines, however, we can obtain from metals and hard substances, a cast like the ordinary stamps, and we can effect the same result by placing two pieces of paper over the object and rubbing the upper one with a black-lead pencil, by which means the paper is forced into every depression. Paper rapidly absorbs the fluid of the solution, and becomes rough, and, therefore, must be treated with various substances, in order to give it a perfectly uniform surface. It may be brushed over with a little drying oil, such as linseed or nut oil, to the former of which I give the preference. The oil should be thoroughly boiled, that it may dry as quickly as possible, after its application to the paper. The substance to which the oil is to be applied, should be clean. It is then to be brushed lightly over with a camel's hair brush till all absorption ceases, and the surface is left shining, owing to the small quantity of oil still remaining upon it. Great care must be taken that the plaster, or paper, be just saturated, and no more, as the superfluous oil, by drying on the surface, will fill up the space between the fine lines. The paper must then be left to dry for about twenty-four hours, and, if possible, exposed to sunshine, as the rays of light favour the absorption of oxygen, a circumstance absolutely essential to the drying of linseed oil. It is then ready to receive some conducting substance, of which I shall hereafter speak. This mode of treating paper appears, for most purposes, to be superior to every other.

Varnishes may be applied for the same purpose, and as

some of them dry more quickly than the oils, their use is attended in some cases with advantage. The principal of these is the white hard, copal, mastic, and carriage varnish. The first dries in a few minutes, and should be applied until a small quantity bears out from the surface. It is best adapted for highly-glazed papers, where the quantity of size prevents the absorption of the more viscid varnishes. The mastic fulfils its purpose very well, but no particular advantages attend its application. The carriage-varnish may be sometimes used, but great care must be taken that it does not clog up the fine lines, otherwise it is a most valuable varnish for this purpose, and leaves a very smooth surface. It would be in vain to describe all the modes which may be adopted to render paper non-absorbent and smooth,—it is the principle to which I wish to direct particular attention. Sometimes a mixture of bees'-wax and rosin previously fused, may be applied, particularly to the absorbent papers. The paper should be held over a flame so that it does not burn, and the composition rubbed upon the opposite side to that on which we desire to make the copy, till the paper is thoroughly infiltrated, when it will be found not to pass beyond the surface. The paper is hard in a few minutes, and ready for the solution. This is an excellent process, and one which may be frequently adopted. Sometimes rosin itself may be used, but it is apt to be brittle. Other substances may be employed in a similar manner, as balsam of Canada, &c.

(140.) The preparation of plaster of Paris is of the utmost importance, and the destruction of its absorbent property is to be effected by means similar to those employed in the preparation of paper. Plaster of Paris is sulphate of lime, or gypsum, deprived of its water of crystallization by heat. In this state it has such an affinity for water, and is capable of taking up so much, that when the powder is mixed with water till it becomes of the consistence of cream, it sets after a few seconds into a hard mass. In the manufacture of

plaster-casts, we must pay attention to several little niceties, in order to get rid of all the air-bubbles. These arise from two causes, either from the adhesion of the air to the plaster, or from the plaster carrying down air with it, when added to the water. The first is to be remedied by using fresh burnt plaster, which is always adopted by the cunning stereotypers, for they state that if it simply stands a fortnight, the casts will not be so good. The workman cannot explain this, but the rationale was well known to Mr. Wyatt, our celebrated sculptor, who told me that he attributed it to the adhesion of the air; and that thus many delicate casts were injured. He places the dry plaster in a saucepan over the fire, and heats it, when it heaves from the discharge of the gas, and is then ready for use. When we desire to make a plaster-cast, a sufficient quantity of plaster should be placed in a basin, and water poured upon it till it is completely covered. The bubbles having ceased to rise the plaster and water are to be thoroughly mixed by rubbing them together. Mr. Williams, in an interesting lecture delivered before the Royal Institution, recommended that a basin of water should be taken, and the plaster gently shaken into it, and allowed to stand for half a minute, when the superfluous water was to be poured off, and the semi-fluid mass remaining being stirred up is then in a state ready for use. Now these two processes are somewhat the reverse of each other, but both agree in principle: that is, by both methods the operator endeavours to get rid of adherent air as much as possible. Some excellent mechanics declare that the first method is the best, others that the last is the only one that can be adopted with success, but as both sets of workmen turn out equally good impressions, we need not be very particular which we follow; in either case, however, we must take care not to over-saturate the plaster with water, for although the plaster will still set, it does not sufficiently harden. For all electro-metallurgic purposes it is preferable to have plasters as hard as possible,

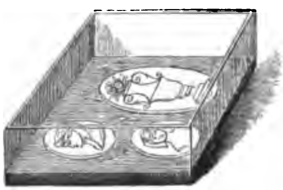
therefore, we must take care to use rather more plaster of Paris in our mixture.

The surface to which it is to be applied, should be slightly brushed over with a very small quantity of salad oil. A little fluid plaster may then be poured on the cast, and with a hog's-bristle painting brush, thoroughly rubbed into all the fine parts, which will prevent the adhesion of any air-bubbles in the plaster which might prevent a perfect impression. Another portion of plaster, sufficient to give the desired thickness is now to be added, and time must be given for the whole to set, when it should be removed from the mould, and gently heated over a fire to drive off excess of moisture. It is then found to be exceedingly hard, and ready to receive substances to destroy its absorption.

The great advantage of plaster of Paris is its applicability to nearly all cases, for it may be employed with all metallic substances. Casts can also be made with the utmost sharpness from sulphur, and it delivers so admirably from moulds of that substance, that the Italians use for their medallions almost exclusively sulphur-moulds. It is even possible to take a plaster-cast from a plaster-mould by previously saturating the mould with boiled linseed oil, but, however, the Italians do not consider these moulds form such sharp casts as those of sulphur. Rough and large objects are occasionally copied from plaster-moulds by simply soaking them previously to the operation. There is no difficulty in taking moulds from wax, bees'-wax, and rosin, stearine, spermaceti, animal, vegetable, or, indeed, almost any organic substance. Plaster of Paris is frequently coloured in various ways to suit the fancy of the operator, and a pretty effect is sometimes produced by using two colours of plaster, one being first employed for the sunk parts of the mould, the other being applied over that to the flat parts, so that when the cast is removed from the mould, all the rilievo is of one colour, all the flat portion of another.

(141.) There are various modes of filling plaster-casts to render them incapable of absorbing fluid. These may, however, be divided into two classes, the application of solid substances, as stearine, wax, &c., by the employment of heat, and of substances in solution, as varnishes, &c. It may seem unnecessary to detail such a variety of modes for obtaining the same object, but as we do not always have the best at our command, we are glad to avail ourselves of some other material which will answer nearly equally well. The application of solid substances rendered fluid through the agency of heat is effected in every case in precisely the same way, a minute description of one will, therefore, suffice for all. This mode of treating plaster-casts is to place them in a flat dish with the material, which should not exceed half the height of the cast, and the heat employed should be sufficient to render the composition perfectly fluid. The heat may be applied by means of a lamp, or gas-furnace, the top of a stove, or the hob of a fire, and the temperature should be raised a few degrees above the melting-point of the substance. The plaster previously to this operation, although well dried, will part with more water, which, passing off in the form of steam, gives an appearance of boiling. After it has remained in this state for a short period the cast is to be removed from the fluid. The temperature at which this operation is performed, influences the success of the process, for if taken out at too low a heat, a portion of the substance, be it wax, tallow, or stearine, will congeal on the surface of our mould, and much impair its sharpness. If removed at too high a heat the fluid remaining upon the surface, will rush into the pores of the plaster, and not sufficiently fill its texture. I like to see the surplus fluid on the surface of the mould gradually and quietly entering, taking its own time, being first absorbed at

Fig. 19.



the circumference, and gradually lessening till the whole has penetrated into the mould. For different processes we require a, more or less, perfect filling. When we are only desirous of using our mould for simply making a metallic reverse, a less perfect preparation will suffice, and fifteen minutes' exposure to heat will be found ample enough; if, however, we want most thoroughly to protect the plaster, the cast must be left for nearly an hour, and boiled at a higher heat till the steam ceases to rise from the mould. If the plaster is thus thoroughly saturated, it will become semi-transparent, and the light of a candle may be distinctly seen through it. When the plaster is cool, a uniformly smooth, polished appearance will be given, and nothing will be left on the surface, if the operation has been properly performed. My experiments on plaster have been more extended than may at first sight seem necessary, because from the first it appeared to me obvious that this was the substance on which electro-metallurgy must be dependant for a very extensive application. Its mode of moulding is comparatively so simple, so economical, and so effectual, that it is applicable from the smallest medallion that the genius of a Wyon can produce, to that gigantic statue of the immortal duke, which, when completed, will be an everlasting monument to the ingenuity of Wyatt.

The substances used to fill plaster need not be lost, for after the mould has been used, by throwing it into hot water acidulated with dilute sulphuric acid, the substance will leave the plaster, and float at the top of the liquid, whilst the water will combine with the plaster, and remain at the bottom of the vessel. My attention was first directed to the use of the acid by Mr. De la Rue. During the immersion of the prepared plaster in the solution, a soap of copper is formed which the acid decomposes and sets free, and thus by this chemical trick we employ our preparing substances over and over again.

There are several analogous materials which may be em-

ployed without difficulty for filling plaster, I generally give the preference to stearine, because it is cheaper and more cleanly than the other substances. From the best stearine we pass by every grade to stearine prepared by pressure, to hard mutton fat, and at length to ordinary tallow. This is well adapted for filling plaster. It is readily melted, and from its fluidity passes into the numerous pores of its texture. It is as well to boil the cast for some considerable time in the tallow, then drain off the superfluity, and, afterwards, leave it in a cool place to harden. By boiling, I do not mean that the tallow should boil, but that the vapour from the plaster should give an appearance of boiling; in general the hardest tallow should be selected, but good candles answer every purpose. The elaine in the tallow, perhaps, helps importantly to protect the plaster, and, therefore, in very large casts is valuable.

Spermaceti also renders plaster non-absorbent, and is to be applied in the same way as the tallow. Spermaceti, as sold for candles, answers the purpose admirably.

White wax, such as that obtained from wax candles, suffices very well to prevent the absorption of plaster, and is very easy to apply.

Equal parts of bees'-wax and rosin previously fused, may also be employed with advantage to fill the plaster. The more rosin contained in the above composition the higher will be the heat required for its perfect fusion, and although rosin will answer by itself, yet it cannot be made to penetrate more than a very short distance into the texture of the plaster, though a hard, clean, non-absorbent surface, can by this means be produced. A solution of rosin in oil of turpentine may be used, but it is difficult to drive off all the turpentine. A mixture of rosin and grease may also be employed.

Fluid substances, and substances in solution are to be applied in the same way as solid materials in a state of fusion,

the greatest care, however, being required to prevent any of the preparation remaining on the surface.

The application of boiled linseed oil is another mode which may be practised. It should be applied to the cast until a very minute quantity remains unabsorbed on the surface; it is then to be dried, and this is best accomplished by free exposure to sunshine. The mere hardening of the exterior film does not indicate a sufficient dryness for the object to be placed in the solution, it being necessary that the oil should be somewhat dry throughout. If the object be placed in the solution previously to its being dry, the oil will separate from the plaster, the solution will act upon the cast, and both cast and solution will be materially impaired, if not utterly destroyed. Plaster requires a large quantity of oil for its saturation, perhaps as much as half of its bulk. The casts should not be over-dried when the oil is applied, as the oil does not then so readily harden.

The same observations which apply to varnishes, balsam of Canada, Venice turpentine, &c., with respect to their application to paper, apply also to plaster articles. Of varnishes, the mastic, and white hard are the best, but the methods described above are superior to those in which any of the varnishes are used. Experiments have been tried upon every other substance likely to be useful, but these it is needless to describe.

I am tempted to give a table of the substances which may be applied to plaster, as a summary of the results of my experiments, taking into consideration their relative efficiency as well as cheapness :—

Tallow	Nut oil
Stearine	Solution of rosin in turpentine
Spermaceti	Balsam of Canada
White wax	Mastic varnish
Bees'-wax and rosin	White hard varnish
Rosin	Lac varnish, &c.
Linseed oil	

Sometimes we are desirous of hardening plaster, which we effect in two ways, either by filling it with a solution of gum arabic, or strong size melted. The French authors state that by these processes we are enabled even to take a clichée from plaster.

(142.) The third class of substances, which comprises those which are acted upon by the metal reduced from the fluid, are few in number ; yet, unfortunately, this class contains one substance which takes finer casts than any other, and that is sulphur. The newly-precipitated metal no sooner comes in contact with the sulphur than it combines with it, forming a sulphuret, and the cast swelling enormously, is quite disintegrated. The only mode of remedying this is to coat the sulphur-mould with a varnish, such, for instance, as white hard and mastic, of which a very thin layer should be applied. Sulphur-casts, however, have not answered well under any treatment, and as we have so many other modes of taking casts, there appears no inducement to follow the subject farther.

Jacobi, indeed, mentions that sulphur may be employed for the reception of copper, but probably it was an inadvertent assertion made by classing it generally with all other non-metallic bodies.

Although sulphur cannot be thus employed directly in the metallic solution, it makes most admirable moulds from which to take plaster-casts. For this purpose a stick of sulphur is melted in a pipkin over a lamp or fire when it is ready for use. The heat should be applied gradually, for being a bad conductor, one part is apt actually to sublime and be on fire before another is in fusion. It is always as well to have a piece of old carpet at hand to place over the vessel should the sulphur catch fire. It may be used for most metallic surfaces, taking care previously either to moisten them with vapour, or to oil them. It may be employed for plaster-casts either wetted with water or oiled, and it may be used to

make a cast from a sulphur-mould. This is rather a nice process, but it is done as follows:—The sulphur-mould is oiled, and the melted sulphur is allowed to remain till very near the point of cooling, when a little is poured into the mould, and immediately poured out again, so that the smallest possible quantity is left. This is allowed to cool, when a little more sulphur is poured in, and again poured out, and these processes of pouring in, and pouring out, are respectively repeated till a sufficient thickness is produced to give strength to the medal. Sulphur is a bad conductor of heat, and is apt to crack to pieces from a very slight exposure to that agent. Sometimes the heat of the hand will make the mould fly to pieces, and even, occasionally, the warmth generated during the solidification of the plaster. It is stated by French authors, that this brittleness is not to be seen for two or three hours after it has been melted, and in that state it may be used for the clichée. Where appearance is an object to the modeller the sulphur is coloured, either with vermilion, charcoal, red chalk, Prussian blue, or plumbago, all of which tend probably, but especially the latter, to render it less brittle. A very general belief exists amongst chemists that sulphur when employed for taking moulds is used in the peculiarly thick state which it assumes after it has been heated to a considerable degree, viz., between 400 or 500° Faht., and plunged into water. Thus treated, it remains for some time in a soft condition, and of a very red colour, but, as far as I can learn, there is no foundation for the opinion.

Sometimes bread-crumbs are used for moulding. The inner part of the loaf of bread is moistened with water, and thoroughly kneaded in the hand, like paste used for catching roach. The substances should neither be so moist as to adhere to the object, nor so dry as not to mould properly. It is, then, to be pressed upon the cast about to be copied. This is not a very valuable mode of proceeding, but some

years ago it was extensively used for what were called bread-seals.

Glue is also, occasionally, employed for moulding. It is melted in the usual way by soaking it in water for twenty-four hours, and then boiling it at a moderate temperature—the glue-pot, in fact, forming a water-bath. The especial purpose for which it is used is to overcome the difficulty which presents itself in moulding any object much undercut, for then the elasticity, flexibility, and general yielding nature of this substance is so great that the most irregular objects may be copied by it. Glue and whiting are much used for picture-frames, and other similar ornaments, but this composition will not prove of much benefit in electro-metallurgy. The last substances cannot be used as the negative pole in metallic solutions, but, perhaps, in some few cases they may be useful to the operator for taking other casts which may be used to receive the metallic deposit.

(143.) Non-conducting substances may be copied or multiplied by depositing a thin film of any conducting substance upon this; and gold, silver, bronze, or copper powder, might be employed for this purpose.

There is another process by which non-conducting substances, such as animal matter, vegetables or minerals, may be coated with the finely-divided metal. The object is to be brushed over with a small quantity of the solution of any salt of gold, silver or platinum, and in that state is to be exposed to the vapour of phosphorus obtained from the evaporation of either an alcoholic or etherial solution, when immediately a deposit of finely-divided metal will take place on the surface. It has been supposed that this is a phosphuret of the metal, but if a little piece of phosphorus be placed in a solution of gold, silver, platinum, or copper, the phenomenon will be explained, as the respective metals will coat the phosphorus. The deposit of copper is particularly beautiful, and it is strange that I cannot find any notice of it.

The substance to be copied may be also brushed over with a solution of any of the metals last mentioned, and exposed either to sunshine or to heat, when reduction will take place; but the process is tedious, and is, therefore, very rarely employed. Any other mode by which the metals may be reduced, would suffice; as, for instance, their reduction by proto-sulphate of iron, or hydrogen gas.

Gilding, silvering, or coppering objects by means of their respective leaves may be employed; yet all these modes are imperfect, and we have no need of any metallic covering whatever, as other means answer the purpose better, and are even more simple and cheaper.

(144.) The best method of giving a non-conducting substance a thin conducting layer, is the application of carbon, either charcoal or powdered black-lead. It is only necessary to brush these substances over the object till the thinnest film is obtained, as that will be amply sufficient for the purpose for which it is wanted. The black-lead is the best, on account of its peculiarly unctuous nature, which enables its application to be made with the greatest ease, either by a camel's hair, or hog's bristle brush, according to the nature of the substance to be covered; care must, however, be taken, that the interstices between the fine lines are not blocked up, as this would, of course, render the duplicate imperfect. Occasionally, there is some difficulty in making a thin film adhere to the surface, but if it be an object where perfect sharpness is not indispensable, a small quantity of varnish may be applied; a proceeding which is suitable to earthenware. Sometimes a little spirit of wine may be used, when a cast is capable of being acted upon by that fluid, as sealing-wax, but great care must be taken not to render the surface rough. Upon many substances, the black-lead may be made to adhere by simply breathing upon the object. In whatever manner we cause its adhesion, it is important always to bear in mind, that it is of

more consequence that a smooth polished surface of black-lead be exposed, than a thick and rougher coating.

The different opinions which are entertained as to the applicability of black-lead for this purpose, are owing entirely to the fact, that great difference exists between samples of that article; for if it be not really carbon, it is absolutely a non-conductor, and I have found a number of pieces totally inactive, while others were most excellent conductors. The action or inaction of different pieces, before grinding, is not all dependent on their hardness, for I possessed a piece of that variety, called by the pencil-makers rock, which completely annihilated the teeth of three of the saws with which I attempted to cut it. I then sent it to a celebrated mechanic, for the purpose of having it sawed, but he succeeded no better than myself; in fact, nothing but a diamond would have made any impression upon it, and yet it was one of the best pieces for voltaic purposes which I ever possessed. Sometimes, on the contrary, hard pieces are of no value, whilst soft ones are excellently adapted for galvanic purposes. There is no method but direct experiment, by which the conducting quality of any particular sample of black-lead can be ascertained. There are not two shops where it can be bought alike, so much being either naturally bad, adulterated, or ill-prepared. Perhaps the best test of good black-lead, is to take a pinch between the finger and thumb, and press it; when, if good, it will cake together and adhere. If charcoal be employed, it should be well burnt, and in the finest possible state of division. The prepared charcoal of the shops exists in the state of an impalpable powder, but it is difficult to apply it.

(145.) Of all these various methods, none is, in my opinion, at all comparable to good black-lead. The thinness of the coating is such, that it is not sufficient, of itself, to carry the voltaic current (for a layer so thin as only to be visible by

reflected light, is sufficient) but this thin layer so favours the extension of the copper laterally, that the whole surface speedily becomes coated. It is very interesting to trace the layer of copper extending itself over any object. For this purpose, a piece of black sealing-wax coated with black-lead, answers best, as the difference of colour renders its mode of precipitation very evident. It will be seen that the copper grows, perhaps, from some point of the wire, on to the black-lead, and gradually extends itself laterally till the whole is infilmed by the metal.

CHAPTER III.

ON THE LAWS REGULATING THE REDUCTION OF THE METALS.

(146.) WHEN we subject any metallic solution to the action of the voltaic current, the metal itself will be reduced, although not always in the same state. Thus, if we dip a knife into a strong solution of sulphate of copper, bright metallic copper will be deposited, but if we use a piece of zinc, a black mass of copper will be thrown down. Again, introduce a piece of zinc into an ammoniacal solution of sulphate of copper and the reduced copper will be bright, whilst, if we dip

iron into a very dilute and acid solution of the sulphate, black metal will be reduced. The learned are divided in their opinions as to whether the metal, in these cases, is reduced by single elective affinity, as they term it, or whether a galvanic action causes the deposit. Perhaps, in the first instance, the iron or zinc having a greater affinity for the acid and oxygen of the salt than the copper, combines with it, forming a sulphate, whilst the copper is thrown down, but as soon as the first portion of copper is deposited, a galvanic battery is formed which increases the action still farther. Be this, however, as it may, the fact I wish to impress in this place is, that the same metal may, under different circumstances, be reduced in different states.

Having shown that the same metal may be reduced in different states, we are next led to ascertain experimentally, what are the circumstances which tend to vary these conditions. We, accordingly, procure a galvanic battery and connect it with two platinum poles, which we place in a vessel to serve as the precipitating trough. In this trough we place a saturated solution of a metallic salt, for instance, copper, when on examination if the battery possesses but feeble power, we shall find that crystalline copper will be deposited; if, however, we dilute this solution with twice, thrice, or four times its bulk of water, the metallic deposit will assume a very different aspect. It will then be aggregated in a flexible state, which, to prevent circumlocution, I shall term the reguline deposit. If we now dilute this same solution to an infinitely greater extent, the metal will still be reduced, but in the form of a black powder, a deposit so fine that the highest power which the skill of a Powell, or a Ross, can impart to the microscope, will not enable the eye to discover the form of the minute particles of which it is composed. Almost all metallic solutions may be substituted for that of the sulphate of copper, and the experiment will show nearly the same result, namely, that the strength of the metallic solution

very materially influences the nature of the deposit. If this fact is really correct, we ought to be enabled to obtain on one negative pole several kinds of deposit, were it but possible to make a solution of unequal strength. Now we can make a solution of unequal strength by placing the crystals of metallic salt at the bottom of a tall glass vessel and pouring upon it some conducting fluid, for, after a little time, if the liquid be examined, the lower part will be found to be of the most intense colour, and contain most metallic salt, whilst the shade will vary to the top from that portion containing scarcely any. For this experiment a solution of sulphate of copper will answer perfectly well. In it we place our electrodes, which may be of copper, and connect them with a single galvanic battery. At the pole joined with the zinc of the battery, copper will presently begin to be deposited; black powder at the top, reguline metal a little below the centre, and crystalline copper at the bottom. If we stir the solution up and thoroughly incorporate it, a uniform metal will be deposited at every point. This experiment confirms our previous view, that the power being equal, the condition of the metal will depend upon the strength of the solution. If we examine the converse of the experiment, and take a solution of sulphate of copper (which should be acidulated to make it a better conductor) and use successively, first one very small battery, then two or three batteries arranged in a series, and lastly, a very intense battery, we shall find that with this self-same solution we can obtain by these means, first a crystalline, then a reguline, and, subsequently, a black deposit. This experiment shows that the amount of electricity passing in any given metallic solution also influences the state of the deposit. From variation of the strength of the metallic solution causing reduction of metals in different states, and from variation in the amount of the power also influencing the state of the metal, we are forced irresistibly to the conclusion, *that to obtain with certainty any particular*

metallic deposit, we must regulate the galvanic power actually passing to the strength of the metallic solution. This is the fundamental principle—the very essence, in fact, of electro-metallurgy—and when we consider from how many causes the one, the other, or both may be interfered with, we begin at once to obtain an insight into the difficulties which the operator must incur in conducting his operations. This grand principle applies to all metals, and even to all the salts of each metal, but as every metallic salt varies in its conducting power, and in the facility with which it yields its elements, great choice is given to the workman to select the salt most applicable to the particular process which he is desirous of performing.

(147.) The laws which regulate the deposit of every metal appear to be the same, and although very simple, yet they have cost me much labour for their developement. The properties of which I have here to speak are strictly those which relate to the quality of the metal, which is so materially influenced by various circumstances. The reduced metal may be precipitated in three different ways; as a black powder, as a reguline metal, (or, in other words, a metal having the properties of ductility and malleability,) and, lastly, as a crystalline deposit. Between these there are, indeed, other intermediate states, or mixtures of two different states, of which we shall hereafter take notice.

(148.) Law I.—The metals are invariably thrown down as a black powder, when the current of electricity is so strong in relation to the strength of the solution, that hydrogen is evolved from the negative plate of the decomposition cell.

The different states which reduced metals assume, as well as the different varieties of each state, appear to be nothing but a difference of aggregation of the minute metallic particles of which they are composed; metals deposited in a black powder are, probably, in an infinite state of division, then,

as a variety of this anaphous mass, we have a spongy material resembling, more or less, the colour of the metal, but the particles of which are still so fine, that it may be moulded with the fingers into any shape we desire. As another variety of this deposit the spongy mass may be aggregated here and there into hardish lumps interspersed in the sponge, and this condition may be so far increased as to give rise to the form which is termed the sandy deposit. Such are the varieties of the pulverulent deposit, the first class of metallic reductions, comprising black powder, sponge and sand.

The cause of these varieties appears perfectly obvious, for hydrogen and copper are deposited at the same time. In a former part of the work we had to treat at great length upon the power of adhesion, which this gas possesses, and if in this place we apply the same fact, we shall see that it will sufficiently account for every variety of the pulverulent deposit. If the hydrogen is evolved in very large quantities, we can easily imagine that it would envelope each ultimate particle of the reduced metal, and prevent the cohesion of the neighbouring atoms. In conformation of this rationale, the metal in this state, notwithstanding its usual colour, is uniformly black, a fact perfectly in accordance with the properties of light. Any substance in infinite division must of necessity be black, from its not having breadth enough to reflect a ray of light, which requires certain definite dimension, which philosophers have measured. If the hydrogen is evolved in smaller quantities, we can easily conceive that some of the atoms of the metal would be aggregated together, forming the spongy deposit, if on the contrary, the quantity of metal deposited far exceeds the quantity of hydrogen produced, we can easily see that more metallic particles would be in conjunction, and, therefore, the deposit would be much firmer. If, lastly, the hydrogen is almost nothing, we can also understand that the particles of sand would be still farther increased in size. Metals of all colours and properties exhibit the same

phenomenon, even silver, platinum, &c., which are usually white, gold, which is yellow, and copper, which is red, together with other metals, obey this law, all being easily reduced as a black powder.

(149.) Law II.—Every metal is thrown down in a crystalline state, when there is no evolution of gas from the negative plate, or no tendency thereto.

When I speak of no tendency to the evolution of the hydrogen, I mean, that the strength of the metallic solution is so great that either electricity of a much greater tension must pass, or the solution must be rendered of more easy decomposition, before gas would be evolved.

This is in fact in strict accordance with the generally-known properties of bodies, for we find, universally, where bodies are deposited quite at their ease, and very slowly, that they have a tendency to assume each for itself some peculiar and definite form. In the deposition of a salt for instance, if it is suddenly precipitated, it always presents itself as a fine powder, which would appear to be almost in the ultimate state of division, but if the deposit takes place very slowly, it will assume some peculiar form. Nothing can be more complete than the analogy between the crystallization of a salt, and the crystallization of a metal, for both agree in their atoms requiring sufficient time to arrange themselves in their own peculiar way. The crystalline condition is not very generally adapted for the purposes of the arts, because the sides of each separate crystal do not firmly adhere to its neighbour, but it is most admirably suitable for coating a reguline deposit, adding a beauty and lustre which it is impossible to give in any other way. If, indeed, the crystals are very slowly formed, each one will have so slight an adhesion to its neighbour, that a piece held by its edge will break from its own weight, and we may even increase this property to such an extent that only solitary crystals may, here and there, be

deposited. In the crystalline state, the brittleness of the metal would appear to be caused by the liquid wetting each separate crystal, and the interval caused by the film of water in the mass of copper, would account for the very slight adhesion that is found to exist.

(150.) LAW III.—Metals are reduced in the reguline state when the quantity of electricity in relation to the strength of the solution is insufficient to cause the production of hydrogen on the negative plate in the decomposition trough, and yet, the quantity of electricity very nearly suffices to induce that phenomenon.

In fact, the reguline state is obtained in the greatest perfection when hydrogen is just at the point of evolution, but yet none is really given off from the negative metal.

(151.) The reguline metal possessed of the properties of flexibility, malleability, and elasticity, seems to be produced by such an arrangement of the ultimate particles of the deposited metal, that, being thrown down in exact apposition, they form a regular mass, presenting frequently at the back of the object, a similar uniform surface to that seen at the front. When we perceive in ordinary metallurgic operations that the same metal may vary much in its properties, that at one time it may be flexible, at another elastic, and at a third brittle; and when we farther perceive that the density of the same metal may vary, that a cubic inch at various times may even differ in weight, we must not be surprised to find that reguline metal formed by electro-metallurgical processes may vary in the same way, and, indeed, we do find that differences of the same nature really occur. To attempt the explanation of these things, would lead us far beyond human knowledge, and carry us to the properties of the ultimate atoms of substances, for, doubtless, these differences are produced by variations in the arrangement of these particles; how otherwise

can we account for the compression caused by hammering a solid body, or the increase of volume from annealing it. To obtain however the reguline metal in great perfection, we should carry on our process with such celerity in relation to the strength of the solution, that at every point of the negative surface, or that at which the metal is deposited, the action should be uniform, and atom by atom of the metal should be so quickly thrown down, that no time is allowed for the particles to follow their own fancies and arrange themselves in crystals. There are, indeed, many little circumstances which interfere with the apparent density of the reguline metal, thus the ultimate particles appear to be thrown down closer together at a low than at a high temperature.

(152.) Dismissing theories, however, we must remember these facts; that the electric power in any solution, when barely sufficient for the production of hydrogen, causes the reduction of the metal in a malleable and ductile state; that the electric power, when not nearly sufficient to cause the appearance of the gas, throws down the metal in crystals; and, lastly, that the pulverulent deposit is produced when there is evolution of the gas.

(153.) A very brief examination of our laws will show that the two properties of galvanic batteries must operate in an important manner in regulating these results, and, accordingly, we find that they are materially modified by the size of the battery and its electro-motive power, or, in other words, by its intensity. The regulation of intensity is, perhaps, of the greatest importance; for on the one hand, economy requires as few cells as possible, and on the other hand, other circumstances require more. Whenever it is possible, the fluid to be decomposed should act on the positive pole of the fluid. Thus, in the decomposition of salts of gold, silver, iron, lead, tin, and copper, we use in the decomposition apparatus, positive poles of these respective metals. This enables us to conduct our precipitations with a single cell,

which, with my battery, enables us to obtain any given amount of work at the smallest possible cost. During the decomposition, the metals mentioned above are dissolved precisely to the same amount as that to which the new deposit is obtained. The solution is in the same way, always of the same strength.

(154.) The degree of action of the fluid on the positive poles, or rather of the oxygen and acid transferred to the positive pole, varies with every salt of the same metal. To regulate the action equally in different cases, acids, either of more or less oxydizing power, or in greater or less quantity, are added to the metallic solution to be decomposed. An increase or decrease of the temperature, influences, materially, the intensity required for different salts, because at a higher temperature the current passes with more facility, and the action on the positive pole is more energetic. These minutiæ have hereafter to be fully discussed; but here I wish to point out, that when possible, one cell only of the battery is to be used, and where this is rather deficient in intensity, a compensation should be obtained by adding to the metallic solutions acids of more or less affinity for the positive pole, according as that may be required, so that if increasing intensity we lessen resistance.

(155.) For those cases where we use a positive pole or anode made of platinum, we are compelled to obtain increased intensity by employing a more extensive series of batteries. In these cases, we must use as many cells as will decompose water; and three or four will in general be amply sufficient. Beyond the mere capability of decomposing water, I cannot perceive that increment or decrease of intensity, as a general use, is of material importance, and the regulation of the quantity must then be made the subject of attention.

(156.) The quantity of electricity passing in any fluid will depend, cæteris paribus, upon the distance between the elec-

trodes, the extent of surface they expose to the fluid, or their relative size one to another. These properties have been already described, when treating of galvanic batteries in general, and do not, therefore, require further description in this place. However, a different quantity of electricity is required for every variation in the strength of the solution; as any increase of the metallic salt requires a corresponding increase in the quantity of electricity; and the converse is equally true.

(157.) The quantity of electricity passing in a solution of copper curiously influences the state of the crystals, for there are two varieties of this deposit, one of which arises from a deficiency of quantity, in relation to the strength of the solution, and in this state the new plate of metal is like an aggregation of sand, in fact, like common sandstone, the particles having no more cohesion or consistence. In this state, the plate of metal is in the utmost state of brittleness, and this, we must recollect, is produced by too small a quantity of electricity in a strong metallic solution. The second variety of the crystalline state of metals, arises from a large quantity of electricity, in relation to the size of the plate; thus, by using a very large positive pole, connected with a battery of feeble intensity, and by employing, at the same time, a strong solution, large crystals, possessing the utmost degree of hardness, will be thrown down.

(158.) To carry into effect these general laws as we may have occasion for them, let us recapitulate the circumstances which may affect them. For this purpose I shall divide the apparatus into its two natural divisions: the precipitating trough and the battery; the variations which may occur in each being placed under their respective heads. Strictly speaking, as the battery and precipitating trough are regulated by the same principles, the variations in each should be alike; but, practically, the arrangement annexed will be found most convenient.

DECOMPOSITION TROUGH.	GALVANIC BATTERY.
Uniform strength of metallic solution	Primitive force of battery
Temperature of ditto	Size of plates of ditto
Conducting power of ditto	Approximation of the plates
Size of positive pole	Conducting power of exciting fluid
——— negative pole	Ditto, of connecting wires
Radiation between the poles	
Approximation of the poles	

By a glance at this table, we perceive seven variable circumstances in the precipitating trough alone, which may change a hundred times during the day, opposed to five variable conditions in the galvanic battery. When we, furthermore, consider that each of these circumstances are not only susceptible of every variety of alteration, but that in each part of the fluid the condition may vary; we perceive that the changes to which every metallic salt may be subjected are infinite. Disheartening as this view of the most favourable process by which our operations can be conducted certainly appears, let us not be overwhelmed with the difficulties presenting themselves, but rather rejoice that this mode of working in metals by unknown agents will never be subjected to blind experience nor to ignorant practice, but will require the constant superintendence of mind, raising electro-metallurgy far above the lower arts.

If we examine the above table in reference to the fundamental principle of electro-metallurgy, — the regulation of the quantity of electricity to the strength of the metallic solution — we find that the strength of the solution being fixed and rendered as certain as possible, all the other conditions relate only to the quantity of electricity which is allowed to pass through that solution. In any fixed metallic solution the deposit is influenced by the amount of electricity passing, according as these conditions in the trough or battery are varied. The more these conditions are exalted,

the greater the quantity of electricity which will pass; the more they are depressed, the less the amount of the voltaic force that will traverse the solution.

(159.) In any given solution we may increase the disengagement of the hydrogen so as to cause a black deposit, by increasing the intensity and quantity of the battery; by a series; by diminishing the size of the negative pole and enlarging the positive electrode in the decomposition-trough; by approximating the electrodes or poles; or, lastly, by increasing the heat. All these conjointly, or any of them separately, will favour the increase of electricity, as they will increase the quantity of hydrogen evolved.

For any given size of the negative plate we can obtain a black deposit, by increasing the intensity and quantity of the battery; by increasing the positive electrode in the precipitating trough; by diminishing the quantity of metallic salt in solution, at the same time adding to its acid, and by approximating the poles.

With any given battery (provided it will decompose water) we can obtain a black deposit, by diminishing the size of the negative pole in the precipitating trough; by increasing the size of the positive; by approximating them, and by rendering the metallic solution very weak with dilute acid.

(160.) To obtain a crystalline deposit with any given solution, we diminish the quantity of electricity, as well as the intensity derived from the battery. We increase the size of the negative pole in the decomposition trough, diminish the positive, and separate them.

With any given negative plate in the trough we can obtain a crystalline deposit, by diminishing the power of the battery; by saturating the solution in the precipitating trough with the salt, and taking care that it is not acidulated. The positive plate may be diminished, and separated from the negative.

With any given battery we can obtain a crystalline deposit,

by strengthening the saline solution in the decomposition trough, and not acidulating it; by increasing the negative electrode, diminishing the positive, and separating them.

(161.) To obtain the metal in the reguline state, is, however, our great object, and to obtain the exact point of evolution of the hydrogen is important and difficult. With any given metallic solution, if we find the hydrogen too abundant, we may either increase the negative pole in the decomposition trough, or diminish the positive, which will suffice in many cases. But in some operations we are desirous of having the electrodes of the same size, and then we diminish the size of the plates of the battery, or the strength of its charge; for instance, I sometimes use my battery charged with water and a faint trace of acid. Again, in other cases we are desirous to increase the rapidity of the process, and then the evolution of hydrogen in the trough will be diminished by increasing the quantity of metallic salt in solution, a modification which will answer every purpose. Variation in the distance between the poles in the trough will be found sufficient, in many cases, to regulate the evolution of the hydrogen.

The temperature at which the solution is kept, will also materially influence the same phenomenon, for the electric fluid passes to a much greater degree at a high than at a low heat.

The converse of all these procedures is equally applicable to those cases where the hydrogen is deficient. By regulating the strength of the metallic solution, and adding more or less dilute acid, the evolution of the hydrogen, in any battery, (provided it be sufficiently intense to decompose water,) will be perfectly under control.

The student in electro-metallurgy will at once perceive, that these three last voluminous directions are perfectly unnecessary to any person thoroughly conversant with the properties of galvanic batteries and the doctrine of resistances, for they

are but a recapitulation of what has been already so fully considered in the book on Galvanism. To recapitulate, therefore, in a few words: to cause the powdery deposit, we diminish all resistances to the passage of the electric fluid; to cause the crystalline deposit, we increase all the resistances, and, lastly, to cause the reguline metal, we must cautiously regulate the resistances according to the strength of the metallic solution.

(162.) Thus, with any amount of salts in solution, with any-sized negative plate, with any-sized battery, and at all temperatures, we can obtain the reduction of any metal in any state we please. It is true that this excessive refinement has hardly been carried to each salt of every metal, yet the principles have been so far accurately demonstrated with such a number of them, as to leave no doubt of their general truth and value.

(163.) To regulate the galvanic power to the strength of the solution will henceforward be my constant theme throughout the concluding part of this volume. Having once begun I shall continue and end with it, that this important point may be so firmly impressed upon the minds of those who practise electro-metallurgy, that they may conduct their processes—not by chance, or blind experience, but—by unerring and never-failing principles; that when the operator desires to make alterations in his battery, his trough, or his solution, he will at once be possessed of the secret of adapting every other circumstance to attain the end he requires. To regulate also the uniform strength of the solution by the proper diffusion of the newly-formed metallic salt, must also be my continued advice; that success may crown the labours, pleasure the success, and profit the pleasure derived from the practice of electro-metallurgy. The want of an uniformity of strength in the metallic solution perplexes the tyro in electro-metallurgy more, perhaps, than any other circumstance; for after having mixed a solution of definite strength, and having taken the greatest pains that the positive and negative surfaces

should be under the same conditions in every part, he is surprised that, frequently, in the same solution, he has every variety of deposit. He, perhaps, in his disappointment, declares that electro-metallurgy depends on chance; but let him only particularly examine the state of the solution, and he will find that, from various causes, the uniformity has been destroyed. At one place the acid will be in excess, and in another the metallic salt. Rays from the sun may have heated the upper part of the solution, which would still remain at the top, as the hotter part being lighter would not cause that circulation which is necessary for the heating of fluids. Sometimes, indeed, the metallic salt would seem to subside to the lower part of the decomposition vessel, leaving the upper part comparatively unsaturated. In the description of electro-metallurgical apparatus, the best methods of regulating the uniformity of the strength of the solution has been already considered, we need not, therefore, further allude to it in this place.

(164.) In detailing the above laws, the battery has been more especially alluded to, because we can, by its means, regulate most exactly the quantity and intensity of the current. The same principles apply to the cases in which the metal on which the reduction is to take place, is made the negative plate to a piece of zinc enclosed in a porous tube, but we cannot adapt this with that nicety which the battery admits.

(165.) The quantity of electricity in a single-cell apparatus, may be increased by enlarging the zinc plate; by approximating it to the negative; by diminishing, as much as possible, any resistance offered; by the use of diaphragms, and by adding to the acid of the solution which acts upon the zinc. The quantity of electricity may, in like manner, be diminished by adopting an opposite course of proceeding. In the use of the single-cell apparatus, as in that of the battery, the strength of the metallic solution to be decom-

posed will materially influence the quantity of electricity required for its reduction. The neutrality of the solution, the acidity, or the nature of acidity, will operate in a similar manner. The different conditions have been sufficiently adverted to, when speaking of the effects of those circumstances in the use of the battery. The above facts alone are sufficient to make forcibly apparent the imperfection of the single-cell apparatus, and the superiority of the process by the battery. The application of iron, tin, and lead for the production of the voltaic fluid, must be subjected to the same regulations as zinc. In these cases, however, the electro-motive power generated is so low, in comparison with zinc, that there is little fear of obtaining a superfluity of the voltaic force, but, on the contrary, such a feeble production of that agent requires us to facilitate its passage, by affording as few resistances as possible.

(166.) There are certain peculiarities appertaining to each metal, and even to each salt of the same metal. Each demands somewhat different management, depending upon the circumstances under which the reduction of the metal takes place. The necessary variation in the modes of operating will be considered in the next chapter.

(167.) And now let us consider the influence which time exerts over these processes. Is it necessary, as all authors have asserted, that the voltaic precipitation should go on slowly? The fundamental laws which regulate the precipitation of metals exclaim at once, by no means! For if the electric power be regulated to the strength of the solution, precipitation may take place at a rapid rate. In fact, we shall hereafter show that the reduction of the metals may be more speedily effected than at first sight appears possible, because the deposition is amenable to the same laws, whether it takes place slowly or rapidly, because the quality of the metal depends on the regulation of the quantity of electricity to the strength of the metallic solution.

CHAPTER IV.

ON THE REDUCTION OF THE METALS.

(168.) To what part of electrical science are we not indebted to Faraday? He has increased our knowledge of the hidden and unknown to such an extent, that all subsequent writers are compelled so frequently to mention his name and quote his papers that the very repetition becomes monotonous. However humiliating it may be to acknowledge so great a share of successful investigation to one man, yet when we come to describe the electro-chemical decomposition of metallic salts, we are forced to render our feeble tribute for his communications on the extended subject of voltaic decompositions. He has shown that we can only reduce metals on the negative pole of a galvanic battery from a solution which contains them in combination with some other substance; for if we galvanize a metal in the elementary state for ever, the voltaic power would have no property to move it to either electrode. He has also proved that not only must the metal be combined in the definite chemical proportion to form a metallic salt, but, in order that it may be decomposed, it must be in that peculiar physical state called liquidity, or fluidity. It is not, indeed, necessary that the salts themselves should be liquid, for if

dissolved in any other fluid they will still yield up their elements to the electric principle. From these considerations it is manifest, that, whenever we are desirous of working in any particular metal by the galvanic fluid, it is necessary first to form some compound of that metal which is soluble in some fluid. The substances with which metals most readily combine are oxygen, chlorine, bromine, iodine, sulphur, cyanogen, and, in some cases, even hydrogen. The compounds of chlorine and bromine are generally soluble in water, giving rise to that class of salts called muriates, or hydrobromates, and are then at once fit for use. The compounds of iodine are, as a class, insoluble themselves, though with hydriodate of potash they frequently form soluble compounds.

Of the metallic fluorides I have had but little experience, and, probably, they will not be much employed for electro-metallurgy.

Most of the compounds of metals with oxygen, or oxydes, are insoluble themselves in water, but become soluble when further combined with acids, alkalies, and certain neutral salts. Thus, oxyde of copper, which is absolutely insoluble, readily dissolves in sulphuric acid, in ammonia, or cyanuret of potassium, &c. Were I to enter fully into these matters, the reader would find himself troubled with an extensive work on chemistry, instead of an epitome of electro-metallurgy, and, therefore, I can only add a very short list of substances which, combining with oxydes, render them soluble in water.

Bromine
Chlorine
Fluorine
Sulphuric acid
Nitric acid
Acetic acid
Tartaric acid,—indeed nearly all the other 200 acids.

Ammonia
Potash
Soda
Bitartrate of potash
Muriate of ammonia
Hypo-sulphite of soda
Sulpho-cyanate of potassium
Cyanuret of potassium.

Metallic salts are generally formed in three ways. The first, where the metal itself being added to the acid and water, the latter is decomposed by the metal, the hydrogen being evolved, and the corresponding equivalent of oxygen combining with the metal produces an oxyde which again unites with the acid to form the metallic salt. The second mode of forming metallic salts when the metal cannot decompose water, is, to add the oxyde already prepared to the acid, and, if necessary, digest it at a moderate temperature. The last mode of making metallic salts, is, to take a solution of the acid which we desire to be the radicle of our salt, and place a very large positive pole of the metal desired to form the base at the lower part of the fluid, and connect it with the terminal silver (s) of a series of batteries (two, three or four, according to circumstances). For the negative pole we use a small piece of metal, and connect it with the terminal zinc of the battery (z).

Fig. 20.

In this way we very readily and conveniently make our saline solution; for the metal being dissolved is retained principally at the lower part of the vessel, whilst the hydrogen is evolved from the negative pole. After a short time, some black powder appears at the negative pole, but as the saturation of the acid progresses, sponge succeeds the black deposit, and sand succeeds sponge, when, if the solution is for electro-metallurgy, the process may be stopped, for we may be perfectly sure, considering the large size of our positive pole as opposed to the negative, that the solution is sufficiently strong.

Sometimes we vary the arrangement by using a diaphragm in the decomposition trough, placing the acid and positive pole on the one side, and on the other with our negative pole some acid to render the fluid a conductor. The cut tumbler, figured No. 7, answers well for these purposes. Occasionally,

instead of an acid we substitute an element dissolved in the water, as iodine, chlorine, bromine, and, occasionally, we employ a neutral salt, the acid of which unites with the metal, whilst the alkali is transferred over to the negative side. Wherever we can use an element or an acid dissolved in water, it is to be preferred to a neutral salt.

The manufacture of salts by the voltaic fluid is generally more expensive than the processes usually adopted, and is, therefore, to be avoided for large commercial operations, especially where the metal is but of little value; yet when we desire a very pure salt, a salt of a very valuable metal, or a salt difficult to form by the ordinary processes, then does the galvanic battery come into play, and under these circumstances, economy, facility, excellence and despatch, are insured by the use of this wonderful engine.

The solution of oxydes in alkalies is to be performed in the same way as the corresponding solution in acids: thus it may be effected by simply digesting the metal in the alkali—a process, however, which should always be discarded in practice from its slow and tedious character. These solutions may be formed by adding the oxydes recently precipitated to the alkalies, or lastly, they may be very conveniently produced by making the metal the positive pole in the alkali connecting it with a galvanic battery. The second process is generally to be preferred, but the latter will frequently be found convenient.

The compounds of the oxydes of metals with salts are generally made by digesting them in a solution of the salt, or by making the metal the positive pole in their solution. The compounds of oxydes of metals with bitartrate of potash and muriate of ammonia, are familiar examples of this class of compounds.

Allied to this last division of metallic compounds is a peculiar class, in which the metal in combination with the bicarburet of nitrogen, or cyanogen, forms an acid which, when

uniting with an alkali, produces a true salt. The union of iron, cyanogen and potassium, has been the longest known under the name of ferrocyanuret of potassium. Some philosophers, indeed, consider this salt as a double cyanuret of iron and potassium, but probably the iron and cyanogen form a distinct proximate element, analogous in the general properties with cyanogen, which again is perfectly analogous to the primitive elements, chlorine, iodine, or bromine.

Almost any other metal may be substituted for iron, and an analogous compound will be formed. Thus, with silver an argento-cyanide, with gold an auro-cyanide, with nickel a nickelo-cyanide may be made. The electro-chemical decomposition of all these substances is peculiar, for under different circumstances different results may be obtained. If placed on the positive side of a diaphragm apparatus, potash will be carried over to the negative pole, where hydrogen is also evolved; whilst at the positive, oxygen is absorbed, and a peculiar compound is left which presently decomposes into a cyanuret of the metal contained in the liquid. To take, as an example, the decomposition of the zinco-cyanuret of potassium, a solution placed at the positive side of a diaphragm apparatus has the potash carried over to the negative pole, while a compound, perhaps zinco-cyanogen is left at the positive electrode, which speedily resolves itself into the cyanuret of zinc. The electro-chemical decomposition of ferrocyanate of potash is the same as that of the above metals.

The formation of the ferro-sesquicyanuret of potassium has been alluded to in treating of electro-chemical decompositions; but Sir John Herschel having lately brought it into use by one of the most elegant and refined chemical processes in the whole range of photography, a more detailed account is here added. The solution of the yellow salt, which may be either completely or nearly saturated, is placed in a large porous tube, and into this is inserted as large a

positive platinum pole as possible. I generally use all the odds-and-ends of platinum I can collect, and string them together with a platinum wire, the object being to bring the pole in contact with as much fluid as possible. The porous tube is placed in a jar containing plain water and a large copper negative electrode, when on the platinum being nected with the silver of a compound-battery of not less than four cells, and the copper with the zinc, half an equivalent of potash is carried over to the outer vessel, and hydrogen is evolved, whilst oxygen is absorbed at the platinum side, and ferrocyanogen is apparently liberated, which, combining with the yellow salt, forms ferro-sesquicyanuret of potassium. Whether other analogous metallo-sesquicyanurets may be formed in the same way I have not been able satisfactorily to determine, the great difficulty being the uncertainty attached to the formation of a hitherto undiscovered salt, for we might make it and still be ignorant of the fact.

Fig. 21.

When the metallo-cyanide is placed on the negative side of a diaphragm apparatus the metal itself is reduced; thus, in one case we actually make the metal pass to the positive platinum electrode, in the other to the negative platinum electrode.

When the metallo-cyanide is simply galvanised between platinum electrodes, the metal is reduced, and, as the result varies with different metals, we shall enter into these circumstances when treating of each respectively, confining our attention, however, to such facts as more especially relate to the electro-metallurgist.

When the metallo-cyanide is galvanised, the positive pole being the same as the metal in the cyanide, the metal, in most cases, is reduced from the salt, and its place supplied

from the solution of the positive pole; in some cases, however, the metal is not reduced, but a salt is formed with the metallo-cyanide and the metal dissolved, the potash being transferred to the positive pole.

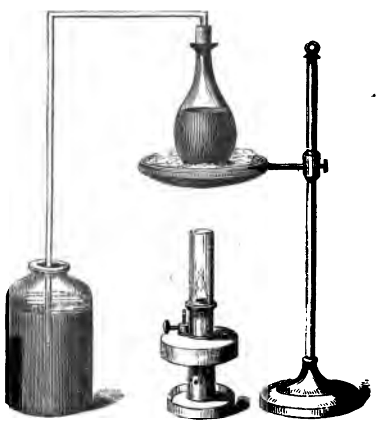
Such is a rough sketch of the general properties of the metallo-cyanides. We have next to consider the mode of preparing this important set of salts, and numerous are the methods by which they may be obtained. They are formed most easily and usually by boiling the oxyde of the metal with the cyanide of potassium; but they may also be procured by adding a solution of the cyanide of potassium to a solution of a salt of the desired metal, but in this case a foreign salt always contaminates the solution. One of the best processes for making metallo-cyanides is to arrange the metal as the positive pole in the solution of cyanuret of potassium. They may even be made by simply placing the metal itself in the solution of the cyanuret of potassium, when it will slowly dissolve in this truly remarkable salt; even gold and palladium are readily taken up in this manner, especially at that part of the solution in contact with the air, which contact seems to favour the action—perhaps by causing a galvanic current, and thereby materially assisting the solution of the metal. Some metallo-cyanides may be even formed by boiling the oxyde of the metal with ferrocyanate of potash, but it is not a very good process. Metallo-cyanides may also be formed by heating together potash, dry animal matter and the metal; when the animal matter affords carbon and nitrogen to form the cyanogen, which then lays hold of the potash and metal to form the metallo-cyanide. This process, with slight modifications, is generally adopted in the arts to form ferrocyanate of potash, which is used upon a most extensive scale. Whether the same process may be adopted for other metals, I am unable to state from direct experience, but, in all probability, many other metallo-cyanides of potassium, or sodium, might be made in the same manner.

The cyanide of potassium so often alluded to while treating

of the metallo-cyanides may be formed in several ways. It may be obtained by heating to a dull redness, the yellow ferrocyanate of potash in a covered iron vessel, filtering and rapidly evaporating it. The objection to this method, however, is, that without great care, the whole of the ferrocyanuret is not decomposed, a circumstance which much reduces its value for electro-metallurgy. By boiling, however, the ignited residue with spirits of wine, this difficulty is said to be overcome, as the ferrocyanate is absolutely insoluble in that menstruum, while the cyanuret at that heat freely dissolves, and is as easily redeposited on cooling.

There is, however, a much better process by which this salt may be formed, namely, by simply transmitting hydrocyanic acid through potassium. Although the modes of making this acid are very numerous, there is but one which is likely to be employed on a very large scale, and that is its formation from the yellow ferrocyanate by means of sulphuric acid. This process is performed as follows: any given weight of the yellow salt is taken and dissolved in about five times its weight of water: this is placed in a retort, or some such analogous vessel, to which is then added a quantity of strong sulphuric acid, twice the weight of the salt, and diluted with three or four times its quantity of water. A pipe is carried from the neck of the retort to the receiving-bottle, which should be kept as cool as possible. For small operations those invaluable vessels, Florence flasks, answer well: a bent tube being connected at one end to its mouth, the other passing into the second vessel; heat should be cautiously applied by means of an Argand lamp, a little vessel of sand being placed un-

Fig. 22.



der the flask, which helps the acid to decompose the salt. Prussic acid is then generated, and passes through the tube to the recipient vessel, which is to be charged with liquor potassæ. When the potash is saturated the operation is completed. The Germans recommend a strong alcoholic solution of potassa to be used in the second vessel, for in this case, the hydrocyanic or prussic acid combines with the potassa, forming a hydrocyanate of potassa, or, the water being abstracted, the cyanuret of potassium, which spontaneously precipitates on the saturation of the fluid, the cyanuret being insoluble in strong alcohol. The ferrocyanate of potash may be considered as containing 3 equivalents of hydrocyanic acid, 2 of potash and 1 of iron; but, unfortunately, we can only obtain half the acid from the salt, owing to the formation of a compound during its decomposition which resists the action of the acid. The decomposition of this salt taking 2 equivalents or 426 grains to avoid fractions, would afford 3 equivalents or 81 grains of hydrocyanic, or prussic acid, capable of forming 198 grains of cyanuret of potassium, whilst in the retort there would remain 384 grains or 3 equivalents of bi-sulphate of potash and 1 equivalent or 174 grains of a peculiar compound, said to contain 3 equivalents of cyanogen, 1 of potassium, and 1 of iron. (Pereira.) It is manifest that, but for this latter compound, we might double the quantity of hydrocyanic acid from the yellow salt. The decomposition just described is the one usually received; but too much reliance must not be placed on its accuracy, for the analysis of the several compounds is too difficult for the results to be fully admitted. The residue left in the retort speedily turns to one of the blues, identical with, or allied to, Prussian blue. This is at best a disagreeable process to conduct, for the hydrocyanic acid formed adheres so strongly to the glass that, instead of being freely given off, bubbles are evolved suddenly with such explosive violence as occasionally to crack the vessel. This may be remedied as far as is possible by the insertion of

plenty of waste pieces of platinum—if platinized so much the better, as that facilitates the escape of the gas. The heat should be applied to every part of the vessel, and the flame should not be allowed to play upon one single part alone. Large commercial operations are performed in green glass or stone-ware retorts.

Now for one word of advice to the tyro. Remember that you are working with prussic acid, therefore, never conduct the process in a room, the fumes being quite as poisonous as the solution of the acid itself; moreover have always a bottle of ammonia, or chlorine, by your side, that should you have chanced to inhale more than is pleasant, it will be instantly at hand to counteract any bad effects. It is stated by Pereira, that a little sulphuric acid or hydroferrocyanic acid passes to the outer vessel, but probably the amount would be of no consequence for electro-metallurgy, otherwise, it might be as well to use a Woulfe's apparatus, and discard the salt formed in the first vessel. To the large manufacturer it may be worth considering whether some other metallo-cyanuret, formed in a similar manner to the ferrocyanuret, might not be more advantageously employed, because the residue of the process last-described contains a large quantity of cyanogen which the acid is unable to set free.

There are other modes of procuring prussic acid, besides the one which has been so tediously described; but these are found to be more expensive. The only one which I shall now notice is the process by which it is obtained from bicyanide of mercury. The bicyanide of mercury itself is formed when peroxyde of mercury is digested with Prussian blue, the peroxyde of mercury abstracting the whole of the cyanogen from the blue, and leaving the oxydes of iron at the bottom of the vessel. The solution may be evaporated to dryness, and one part of the salt dissolved in six of water; one part of muriatic acid sp. gr. 1·15 is then added, and the solution distilled, when the whole of the hydrocyanic acid

passes over, and by being conducted into a solution of potassa, as in the former process, forms cyanuret of potassium. This process, though easier than the first described, is rather given as a resource under peculiar circumstances than as one to be adopted by the large manufacturer. The expence is the only objection, but in a small quantity this cannot be a consideration.

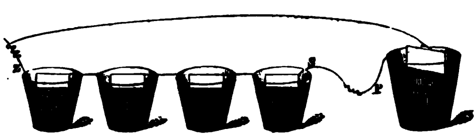
In giving this very rough outline of the general mode of forming salts, the minutiæ necessary for chemical work have altogether been avoided; and those parts alone are entered upon, which are more immediately necessary for the electro-metallurgist to know and practise for himself. This will account for the long description of the cyanuret of potassium, whilst the preparation of the equally important and even more used acids, the sulphuric, muriatic, &c., commonly found in commerce are altogether neglected.

(169.) Having now described the kind of compounds necessary to be employed for the reduction of the metals, and their general preparation, and having already treated of the laws regulating the reduction of the metals in various states, the substances on which they may be reduced, the various apparatus in which the processes may be conducted, and, moreover, described the various forms of galvanic batteries, their properties and manipulations, we are, at length, in a condition to consider the precise manner in which each respective metal may be reduced from its soluble compounds.

Platinum is the first metal of which we have to consider the reduction. There are not many compounds of this metal: the principal being the chloride, the sulphate, and the compounds of chloride of platinum with alkalies. The chloride of platinum is formed by digesting platinum in nitro-muriatic acid, consisting of one part of strong nitric to two of muriatic acid. If evaporated to dryness, at a moderate heat, it forms the chloride of platinum. This salt is a most ready conductor of the galvanic fluid, and, therefore, might be employed with

great advantage, were it cheap enough for a Daniell's battery, instead of sulphate of copper. When we desire to obtain the black powder of platinum, this is the salt to be selected; if acid, it requires great skill to obtain any other deposit from it. To obtain the black deposit, the zinc single-cell apparatus is generally to be preferred. The same deposit may also be obtained by the compound battery decomposition apparatus, by using five or six cells of the battery, charged with the usual strength of acid, and by using a large positive platinum pole in the trough. Unfortunately, the oxygen has always to be evolved on the positive pole, as the platinum does not dissolve, except to a very trifling amount, and fresh chloride of platinum must continually be added to maintain the strength of the metallic solution. This applies to all salts of platinum, as in no case is the positive pole acted upon sufficiently to supply the place of the metal reduced from the fluid. To obtain the reguline deposit of platinum from this solution, we must of course overcome resistances at all points of the circuit; we must begin by employing a very small battery feebly charged, and use a fine positive wire in the trough, combined with a very strong solution of the chloride of platinum. A compound odds and ends' battery is well adapted to obtain the reguline deposit, the little glasses, of which the battery figured below is composed, need not contain more than an ounce of fluid, and four arranged as a series will be amply sufficient.

Fig. 23.



At the bottom of each glass a little mercury is placed, containing a piece of zinc; a piece of silver wire, either amalgamated or coated with some non-conducting substance, except at the end, is immersed in the mercury, and passes to a small piece of platinized silver in the next vessel; the first piece of silver and the last zinc

of the series being attached to a binding-screw, or mercury cup, for the convenience of making metallic connections. In the battery figured, the ends are left free. The batteries are charged with dilute sulphuric acid, and a fine platinum wire is connected with the extreme silver of the battery, and the object to receive the reduced platinum with the terminal zinc. This solution of platinum will bear but a very feeble current when we desire the reguline deposit. Oxygen and chlorine are evolved abundantly from the positive platinum wire, which must not be immersed more than half an inch in the solution, and frequently the insertion of $\frac{1}{8}$ or even $\frac{1}{16}$ of an inch will amply suffice. If the solution of the chloride of platinum be strong, the fumes of the chlorine will, at length, fill the whole room in which the operation is conducted.

Chloride of platinum forms double salts with several alkalies. The ammonio-muriate and potassio-chloride are very insoluble, but the sodio-chloride of platinum, or, perhaps, more correctly, the platino-chloride of soda is very soluble in water. This forms an excellent compound, and perhaps the best for the reduction of the metal in the reguline state, the mode of proceeding being precisely similar to that of the last-described salt. In fact this is, perhaps, the best salt for these purposes, and as scarcely any metal reduces the platinum spontaneously from the solution, they may be indifferently employed as a negative pole in it.

With the electro-chemical decomposition of the sulphate of platinum, I am practically unacquainted; but it is said to form a soluble salt.

If hydriodate of potash be added to a solution of chloride of platinum, a precipitation ensues, which is soluble in excess of the precipitate. It forms a very dark-coloured solution from the presence of iodine; to counteract which, a little free potash is required. It is an unfavourable salt for electro-metallurgy, especially for the reduction of reguline metal.

A platino-cyanide of potassium has been described by some

authors, but it appears a difficult salt to manufacture. It can neither be made by galvanism nor by allowing the metal to stand in the cyanide. If chloride of platinum be added to cyanide of potassium, some change takes place, but I have not succeeded in making any advantageous use of it for electro-metallurgy.

A hyposulphite of platinum may be formed by adding the hyposulphite of soda, or potash, to the chloride of platinum; but this, likewise, forms a very indifferent solution for electro-metallurgy.

The equivalent of platinum being ninety-nine we obtain three times more in weight for our equivalent of power, than we should of copper, or three times more than the zinc dissolved in each cell of the battery; but inasmuch as we know no method of dissolving reguline platinum at the positive pole, at least, to any useful amount, we cannot employ a single battery, but require a series of three or four to effect that object. If we apply our equation to ascertain the cost of reducing platinum, we find that, as platinum in solution is worth about £20. per lb., the value of the power to be added to this would barely exceed 11*d.*; but if the single cell could be adopted advantageously, the galvanic power sufficient to effect that object would not exceed 4*d.* This aspect of affairs is so exceedingly promising that, doubtless, some manufacturer of platinum will enter into the galvanic process on a large scale to ascertain whether electro-metallurgy might not triumph over the Woolastonian method of working in this metal. The one mode, we have seen, requires a battery of almost nominal value, the other apparatus is of the most complicated and expensive nature; so that by ascertaining the labour required for each respective process, the relative time occupied by them, and the quality of the metal reduced being once learnt on the large scale, the question would be satisfactorily determined.

(170.) Gold is rendered solvent by combination with se-

veral substances, and its chloride, bromide, iodide, cyanide, and other compounds, all merit separate attention.

The chloride of gold may be formed in various ways; by passing a stream of chlorine through water containing gold in that fine state of division termed by assayers brown gold. For obtaining a solution of this salt, however, such a method is but seldom adopted, as the metal is more commonly subjected to the solvent powers of aqua regia—a composition of one part nitric to two muriatic acids. The gold is placed in three or four times its weight of this acid, and a moderate heat is applied to favour the action. In this case the nitric acid being a highly oxygenated compound, and the muriatic containing hydrogen, mutually re-act on each other. Nitrous gas is evolved, water is formed, and chlorine set free, which then combines with the gold to form the chloride. By this mode of proceeding the compound is always acid, which is best removed by very carefully evaporating it, when, on cooling, crystals will be deposited. If the operator conducts his process at too great a heat, he will find that a part, or the whole, of the gold will be deposited in the metallic state, and he will be compelled to re-dissolve it. Having avoided this difficulty, and obtained a chloride of the metal, he will find it to be a very soluble salt and an excellent conductor. This salt may be reduced by the single-cell process, which, however, for gold should always be discarded, or by the battery apparatus. In either case the hydrogen appears to have a great tendency to be evolved, and, therefore, the deposit of black powder is easily accomplished. For its reduction in the bright reguline state we must increase resistances. By using a very fine platinum pole, which affords the greatest resistance to the voltaic current, I have worked a solution of this salt quite colourless, and still obtained a reguline deposit. Some better salts are now known, however, for obtaining this object more readily. If the battery apparatus be employed, then we may use a series

of three or more batteries, with a fine platinum wire. If we use a gold positive pole in this solution, a little is dissolved; but it affords nearly as violent a resistance to the passage of the voltaic current as platinum, the oxygen seeming rather to prefer to be evolved than to combine with the metal. This solution of gold is decomposed by nearly all metals, and is, therefore, objectionable on that account; carbon and platinum alone having no effect on it.

The bromide of gold is readily prepared by adding a little bromine to the brown gold of the assayers, and allowing it to remain some time under water, or assisting its action by a gentle heat. It forms a salt of a lovely bright crimson colour, but in its general properties is precisely similar to the chloride, except, perhaps, that a gold positive pole is rather more quickly acted upon in it.

Chloride of gold is soluble in æther, and in this state has long been used for gilding penknives, and other steel articles, by simple immersion. It may be used, but possesses no peculiar advantages for electro-metallurgy. Copper and silver rapidly reduce the metal from this solution. I have endeavoured to dissolve the chloride in naphtha, oil of turpentine, essential oils, and other fluids, thinking that by these menstrua its conducting power might be lessened, but, unfortunately, the gold is reduced slowly from contact with these substances.

The hyposulphite of gold may be formed by adding the hyposulphite of soda or potassa to the chloride of gold. The solution though not decomposed by copper or silver, does not answer well, as the reduced gold is apt to peel off from the object, and it seems as if some other substance was reduced conjointly with it. Gold will dissolve when made the positive pole in this solution.

Chloride of gold forms double salts with certain alkalies, especially soda and potash. They are made by simply adding the alkali to the metallic salt. These compounds

might be used for electro-metallurgy, as they are not very readily decomposed by silver or copper, which may, therefore, be used as negative poles. These compounds, however, are very inferior to the aurocyanuret of potassium, and the gold reduced from them frequently has the appearance of the brown gold of the assayers. Sometimes magnesia or lime may be added to a solution of the chloride of gold with advantage.

If a solution of iodide of potassium be added to a solution of gold, a precipitate of iodide of gold takes place soluble in excess of the precipitate. It requires the addition of free potash to combine with any iodide that may chance to be set free by the acid in the chloride of gold. A gold positive pole is slightly dissolved in this solution, but it has the disadvantage of yielding up its metal to silver by elective affinity, or else it might, perhaps, be employed, though by no means the best solution for this purpose.

The sulphocyanide of gold is insoluble in water, but dissolves pretty freely in sulphocyanide of potassium.* It has the advantage of not being decomposed by silver or copper. A plate of gold dissolves with moderate rapidity when arranged as a positive pole in the liquid. It may be decomposed in all the various ways that have been so frequently alluded to.

We have now to treat of the most important salt of gold for electro-metallurgy, the aurocyanide of potassium. It was first employed by Elkington, whose discoveries we shall fully consider in our history of electro-metallurgy. It is a salt somewhat analogous to the ferrocyanate of potash, and is easily prepared in a variety of ways. It may be made by simply placing a piece of pure gold in a solution of cyanuret of potassium, but this process requires some little time. It

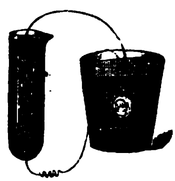
* The sulphocyanide of potassium is a troublesome salt to prepare; but Mr. Low, the patentee of the celebrated Prince's or Naphtha Gas, informs me that large quantities are thrown away in the refuse of the gas works.

may be formed by arranging a piece of pure gold as the positive pole in a solution of cyanuret of potassium, using, at the same time, a small negative pole. It may be also formed, and this is the process that many prefer in the large way, by boiling the oxyde of gold for half an hour in a solution of cyanuret of potassium; the fluid may then be poured off, and is ready for use, whilst the remaining oxyde of gold is to be carefully preserved. Of these three processes, to the second I should unhesitatingly give the preference, for by using a strong battery a large quantity may be made in a few minutes, and it only requires the metal itself, and not the oxyde, in the production of which alone more trouble and time is incurred than is consumed in the entire manufacture of the salt by galvanism. The galvanic process of making salts has been already so fully described that no further detail is here required, only remembering to have a strong battery, a large positive, and a small negative pole. There are still other modes by which this salt may be made; it is, for instance, produced by simply adding the soluble salts of gold as the chloride to the solution of the cyanuret of potassium, or by digesting insoluble compounds of gold, as the sulphuret, in the same solution. It may also be formed by digesting the oxyde of gold in a solution of ferrocyanate of potash, and in this case the presence of a little of the latter salt is not very material, but on the whole we had better, perhaps, employ the pure metallic salt.

The auro-cyanide of potassium having been formed is at once ready for the electro-metallurgist, and it is quite a matter of indifference whether it contains a little free potash, or a little cyanuret of potassium. The solution may be of any strength; the stronger, however, is to be preferred, as this salt is by far the best adapted for reguline metal. The metal may be reduced from it by the single-cell process, for which a large zinc plate would be required. However, no one should ever think of employing this process, as by its

means we should reduce our gold from the solution, and our cyanuret of potassium would be wasted. Of the battery processes, the compound battery, with a platinum positive pole, may be employed, but, unless under very peculiar circumstances, is better discarded. The battery-process with a gold positive pole is, therefore, our resource for this salt. As a general rule the gold positive pole should be about the size of the negative pole, or that in which the reduced gold is being deposited. A single battery will in general suffice, the gold being attached to the platinized silver, and the object to receive the deposit to the zinc. A very small battery will be required, a platinized silver wire for small objects being almost sufficient. The battery here figured is formed with a glass tube drawn to a point, a fine platinum wire being melted into the glass, so that a little piece is left inside, and the rest on the outer part of the tube; some mercury with fragments of zinc are placed in the vessel sufficiently high to cover the wire: the tube is filled with dilute sulphuric acid: and, last of all, the apparatus is completed by the insertion of a platinized silver wire.

Fig. 24.



The process, when a gold positive pole is employed, is materially influenced by the quantity of free cyanuret of potassium in the solution, as a deficiency of that salt causes the action to take place very slowly, whilst an abundance so much increases the action, by dissolving the positive gold pole with great rapidity, that the deposition is very speedily effected. The wood-cut exhibits the mode I am adopting to make a light sovereign heavy, by adding a little gold to its surface. Any other form of battery may be employed instead of the small one figured, taking care to adjust it according to the three laws already detailed. One of the little batteries figured above for the reduction of platinum may be very conveniently used.

The reduction of gold by galvanism is accomplished at a low rate, for as the equivalent of gold is very high,* and its value great, we find the galvanic process a most advantageous mode of proceeding. We obtain for one equivalent of power, costing $\frac{1}{20}$ of a penny, 200 grains of pure gold, worth about £2.; and, therefore, 1lb. avoirdupoise of gold would be reduced for less than twopence, and the gold so reduced would be worth nearly £70.

(171.) Palladium is a noble metal, but has the singular defect of being brittle when hot. It would be extremely valuable were there to be found any great consumption for it, but the supply happens to exceed the demand; and, therefore, it is moderately cheap, considering that its usual mode of manufacture is similar to that in use for platinum. There are various salts from which it may be reduced: its nitrate, its ammonio-chloride, and its palladio-cyanide, are the principal I shall notice.

The nitrate of palladium is formed by digesting the metal in nitric acid, and the process is facilitated by the addition of a few drops of muriatic acid. It is a ready conductor, and in its general electro-metallurgical characters is precisely similar to the chloride of gold, or platinum. It is better adapted for the reduction of the black powder than the reguline metal. The palladium is reduced from this solution by many metals, and perhaps only carbon, gold, platinum, and palladium, can be used as a negative pole.

The ammonio-muriate of palladium is very soluble in ammonia, and is the best salt for obtaining the reduction of palladium in the reguline state. The compound battery apparatus is to be preferred for this purpose, two or three cells being required. In the decomposition trough, the positive pole should consist of a very fine platinum wire, which should

* I have assumed the usual chemical equivalent of gold, 200, to be its voltaic equivalent, but have no authority for that assumption, as Faraday, the only authority on this subject, has not determined it.

be immersed only to a moderate extent in the fluid. This salt is not readily decomposed by other metals, and on that account nearly all may be used as a negative pole to receive the palladium. During the decomposition the positive pole has a bright yellow powder deposited upon it, giving it the appearance of being converted into gold.

The iodide of palladium is formed by adding iodide of potassium to a solution of palladium. It may be dissolved in excess of the precipitant. It is by no means a valuable salt for electro-metallurgy.

The palladio-cyanide of potassium may be formed by simply immersing palladium in a solution of cyanide of potassium, when it will be gradually dissolved; or it may be made by galvanism, or even by boiling the oxyde in the cyanuret of potassium. It may be employed with a palladium positive pole, or with a platinum positive pole, but the former is to be preferred.

The reduction of palladium is accomplished at a low cost, as far as the materials are concerned, for palladium being a valuable metal and a high equivalent, requires but a small amount as the cost of galvanic power to be added to the value of its solution.

(172.) Iridium has but few soluble salts; of these however the chloride may be mentioned. The black deposit of Iridium is easily reduced from its solution, and is very frequently found on the platinized silver of commerce, which is, perhaps, the only fact concerning the metal worth recording. I have reduced this metal in the bright reguline state, but only on a small scale.

(173.) Rhodium forms soluble salts, of which the only one I have subjected to the voltaic fluid is the sodio-muriate. It was decomposed with a compound battery of ten cells with platinum electrodes, the positive consisting of a very slender wire, — at the negative a deposit of rhodium took place. It was of a whitish colour, and might be stripped off from the platinum in small pieces, but was very brittle.

A black powder was deposited by a more powerful voltaic current.

(174.) Osmium has a soluble oxyde, but subjected to the voltaic fluid between platinum poles it did not yield reguline metal but a black deposit, which appeared to be the metal in a lower state of oxydation than the volatile soluble oxyde, and not the black powdery metallic deposit.

(175.) Silver, on account of its universal importance, demands our most serious attention. The nitrate, sulphate, acetate, hypo-sulphite, ammoniuret, and several others, must be separately considered, though the argento-cyanide of potassium is most decidedly entitled to the preference.

As a solution, from which the silver is to be reduced, the nitrate is for all purposes the most unfavourable. When this salt is used, the hydrogen has a great tendency to be evolved from it, and therefore a relatively feeble current must be employed. The decomposition cell may contain a positive pole of platinum, or even of silver, as the latter will, by being dissolved, always maintain the same state of saturation of the fluid. When we use a positive pole of silver, there is a risk of materially increasing the quantity of electricity, and therefore only a silver wire should be employed; and then the distance at which the operator places them in the fluid, will accurately regulate the amount of current. The negative pole to be placed in this solution, for the purpose of receiving the precipitated metal, may consist of either gold, platinum, charcoal, or silver; but the other metals are not at all fit for the purpose, owing to the energy with which they decompose the solution. The strength of the solution of this salt may be from ten to four hundred and twenty grains to the ounce of water, taking care that the electricity is regulated in its quantity, according to the strength of the solution, in the manner already directed.

The sulphate of silver is easily formed by adding sulphuric acid to a saturated solution of nitrate of silver, as, by its

being far less soluble than the nitrate, it is very quickly deposited. The supernatent liquor is to be poured off and well washed with a little distilled water, when it is ready for the operator. It is not so easily decomposed as the nitrate, nor so ready a conductor, but it is a very inferior salt for electro-metallurgy, as the silver, under the most favourable circumstances, is very brittle.

The acetate of silver is formed in an analogous manner to the sulphate, and in its conducting power and facility of decomposition much resembles it. In both these cases a silver positive pole may be employed in the decomposition apparatus, and a single battery of small power for the source of electricity.

The hypo-sulphite of silver may be readily made, by adding any hypo-sulphite, such as that of potash, to the nitrate, chloride, or any other salt of this metal. There appears to be a strong attraction between silver and this acid, as the hypo-sulphite decomposes the most insoluble salts of silver. The hypo-sulphites of the alkalies may be prepared by adding sulphurous acid to their sulphurets; as, for instance, to the sulphuret of potassium or sodium. This salt of silver is pretty soluble, and will bear a larger quantity of electricity for its decomposition than the nitrate, sulphate, or acetate, but generally the hypo-sulphites are not well adapted for electro-metallurgy, and in this case the metal is apt to be brittle. A silver positive pole dissolves in this salt.

The ammonio-nitrate and ammonio-chloride of silver are very soluble salts. Great care is required in the use of these salts, for if the solution, by being kept for some time, be allowed to evaporate, so as to leave dried portions adhering to the sides of the vessel, it can no longer be even touched with safety; for a fulminating salt is thus formed, which, if merely touched with the finger, in order to remove it from the sides of the vessel, will explode with mischievous and

awful violence. I take particular notice of this fact, as I nearly lost my right eye in learning it. These salts are good conductors, and their solutions may be used of any strength. They should invariably be alkaline, from excess of ammonia. A negative pole, suitable for the reception of the silver, may be made of platinum, gold, palladium, carbon, or silver itself; all of which are unaffected by the solution, and thus whenever we desire a duplicate of silver, the original should always consist of those metals.

A very fair solution for the reduction of silver is the ammonio-carbonate. It is formed by adding carbonate of ammonia in large excess to nitrate of silver. Carbonic acid is disengaged with effervescence, and a white powder is deposited, which, on further excess of the ammoniacal salt, becomes soluble. It may be used with a silver positive pole, a mere wire sufficing, and a single battery.

The iodide of silver produced by adding iodide of potassium to the solution of nitrate of silver, and dissolved with excess of the precipitant, may be employed for electro-metallurgy. It is not decomposed by copper, and may be used with a silver positive pole and single battery.

The sulpho-cyanide of silver formed by adding sulpho-cyanide of potassium to the nitrate of silver, and then dissolving the precipitate with excess of the sulpho-cyanide, may be employed like the iodide. A positive pole of silver dissolves in this solution.

A potassio-tartrate of silver is formed by boiling oxyde of silver in bitartrate of potash. It is easily decomposed by light, and possesses no advantage for electro-metallurgy.

The spongy mass can be obtained from any of these salts, with the utmost readiness, by increasing the quantity of electricity.

In the electro-chemical decomposition of nearly all the above salts of silver where the positive pole consists of the

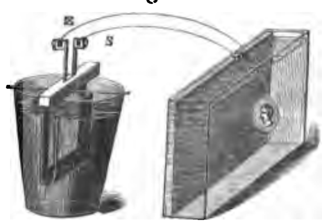
same metal, a black crust is very frequently observed on the silver which very probably is a peroxyde of silver analogous to the peroxyde of lead, &c.

We have, at last, to treat of by far the best solution of silver for electro-metallurgy, which is the argento-cyanide of potassium. This may be formed by digesting the oxyde of silver with ferrocyanuret of potassium, but this constitutes a very imperfect process. It may even be prepared by adding any soluble salt of silver to a solution of the cyanuret, or even by digesting the insoluble salts in the same solution, but in these cases, a new salt is formed between the radicle of the salt of silver, and a part of the potassium besides the part required for the formation of the argento-cyanuret of potassium; thus chloride of silver and cyanuret of potassium form chloride of potassium and argento-cyanide of potassium. It is far better to prepare it by boiling a portion of the oxyde of silver for a few minutes in a solution of the cyanuret of potassium, and pouring off the supernatent liquor; the undissolved oxyde is to be washed and carefully preserved for subsequent operations. The best mode, however, of preparing this salt is, to make a large silver plate the positive pole in a solution of cyanuret of potassium, using, at the same time, a very small negative pole in connection with a strong battery, and continuing the process till reguline silver begins to be deposited at the small negative pole, when the operator may be perfectly well-assured that for all larger negative surfaces his solution is sufficiently strong: the little superfluity of cyanide of potassium, by favouring the conducting power of the solution, facilitates the reduction of the metal. The argento-cyanide of potassium, if suffered to crystallize, forms clear, colourless crystals, and the solution should also be colourless. If it is at all yellow, it shows the presence of ferro-cyanate of potash, which it sometimes contains in commerce.

However formed, this salt, first used and patented by

Elkington, is by far the best adapted for electro-metallurgy. It may be employed of any strength, the nearly saturated solution being preferable, and it should always be placed in a glass or stone-ware vessel. It may be reduced by the single-cell process, taking care to use on the positive side of the diaphragm apparatus a very large plate of zinc, with a solution containing a little muriate of ammonia, or common salt; but no electrician would ever think of employing this apparatus for the reduction of silver, for the cyanuret of potassium in combination with the silver would be wasted. The compound battery apparatus with a platinum pole may be used, but should, as a general rule, be discarded, and the single battery apparatus invariably be employed. The positive pole may be the same size as the negative, and should consist of a piece of thick silver sheet, one-third of an inch or more in thickness. The battery need not be very large, for the conducting power of the metallic solution being low, only a moderate quantity of electricity passes. For small drawing-room operations, a tumbler battery with a glass precipitating-trough forms a most elegant instrument for amusement, and the largest manufacturer has only to increase the size of his trough, which should be glass or stone ware, and regulate the size of the battery to it. The plate of silver must be connected with the silver of the battery, and the object to receive the deposit with the zinc. The presence of even a large portion of ferrocyanate of potash in a solution of the argento-cyanide is of little consequence in strong solutions, but in very dilute ones the positive pole becomes covered with a white deposit of ferrocyanate of silver, which materially retards the action. The presence of free cyanuret of potassium adds to the conducting power of this salt, and much facilitates the quickness of the deposition of the metal, and therefore as much should

Fig. 25.



be contained in the solution as can be added without causing the metal to be thrown down in the various states of spongy deposit. The metal reduced from the salt, especially if reduced with the utmost speed that the strength of the solution will allow, is as perfect in its physical properties as the best rolled metal, combining elasticity with softness and flexibility, and the decomposition may take place to any extent.

The reduction of silver metal is very easily performed, and is economical. The equivalent of the metal is 108, therefore, for one equivalent of power, costing $\frac{1}{20}$ of a penny, we obtain that quantity of silver, or the reduction of 1lb. avoirdupoise of silver, worth £4 4*s.*, would by the simple battery process cost less than fourpence. For further particulars of the cost of the reduction of this metal, the student is referred to the equations and data given in a former chapter.

(176.) Nickel is the last in the list of noble metals, being the most ignoble of that class. The nitrate of nickel, the sulphate of nickel, the ammonio-nitrate and sulphate of nickel, the nickelo-cyanide of potassium, but especially the chloride of nickel, require consideration. The nitrate of nickel is very soluble, but the metal has no great inclination to be precipitated, for the hydrogen appears rather to prefer being evolved than to reduce the metal. If the compound-battery process be used, the positive pole should consist of a fine platinum wire, and should only be immersed for a short distance in the solution. The sulphate of nickel is also a soluble salt, and the metal is reduced more readily from it than from the nitrate. It is best reduced by the compound-battery process, with a platinum positive pole, though a nickel positive pole may be employed. When we employ either the nitrate or sulphate of nickel for electro-metallurgy, it is preferable to use the solution as strong as possible. Of the compounds of these salts with the alkalies, those of ammonia deserve the preference, and the ammonio-nitrate, and the ammonio-sulphate may be used for the reduction of this rather troublesome metal.

Nickel forms a compound with the cyanide of potassium by boiling the oxyde in a solution of that salt, which takes up a considerable quantity. The solid salt is of a yellow colour, though the solution generally is of an orange tint. Even in this solution, the hydrogen seems much rather to be evolved than to reduce the metal, and for this reason we must have a very feeble power in relation to the strength of the solution.

The acetate of nickel is easily formed, by adding pyroligneous acid to the oxyde of nickel. It forms a green salt, and may be decomposed either by the compound-battery with a platinum pole, or even by using a nickel positive pole; but it is a bad solution for obtaining reguline metal, though the black powder can be obtained with ease.

The chloride of nickel is formed by digesting the metal in muriatic acid. It forms a fine green-coloured salt, and a very excellent one for our purposes, as hydrogen in this case has not nearly so great a tendency to be evolved. It may be used with a nickel positive pole with one or two batteries, or with a series of two, three, or four little odds and ends' batteries, and a platinum positive pole. The nickel so deposited has a peculiar white brilliant lustre, looking almost like glass,—this deposit is so very beautiful, though brittle when removed from the negative pole, that its examination would amply repay any person taking the trouble to precipitate it. It is such a contrast to the nickel of the shops, that no person would ever suppose that there was any similarity of composition between the substances, still less identity. For practical purposes this salt is perhaps to be preferred to all the others which have been mentioned, and, next to the chloride, the sulphate is the best for the reguline deposit.

Any of the above solutions will yield readily the pulverulent deposit by using a very strong galvanic current.

Nickel possesses but a low equivalent, only 28 grains being deposited for one equivalent of power worth $\frac{1}{20}$ penny. The

voltaic reduction therefore of an avoirdupoise pound worth 7*s*. would amount to about 1*s*.

(177.) Copper requires more than ordinary examination, because the purposes for which its reduction by voltaic electricity has been applied are far more numerous than those of any other metal. Its reduction may take place from several of its salts, of which the sulphate, muriate, nitrate, and acetate, are the most worthy of attention. The sulphate is most commonly used, because it is the cheapest. It deposits thirty-two grains of pure metallic copper, for every hundred and twenty-five grains of the sulphate, decomposed by the voltaic current, and thirty-two grains of zinc are dissolved for every thirty-two grains of copper which are reduced. In the use of all the salts of copper we must call to mind the function of water in voltaic arrangements to dissolve the newly-formed metallic salt; and, therefore, we must take care never to employ solutions of the salts of copper at the utmost degree of saturation, but have a superfluity of that very important agent in our arrangements. Copper may be very readily reduced from a dilute neutral solution of the sulphate, and, in fact, from a solution of any strength, according to the laws given for the reduction of metals. It is, however, a salt of rather difficult decomposition, and offers considerable resistance to the passage of the electric current. Its conducting power, and, therefore, its facility of decomposition, may be increased by adding acid to the solution, which may be either dilute sulphuric, or dilute nitric. A solution, made by dissolving one pound of the salt in four pounds of water, and by afterwards adding from one-third to one-half of its bulk of dilute sulphuric acid, is best adapted for many purposes. The dilute acid should consist of one part sulphuric acid to eight of water, well mixed together. This solution answers extremely well, when we have to cover non-conducting substances, to which a metallic or black lead covering has been given; because the hydrogen, with a sufficient battery, has not such tendency to be evolved.

A variation may be made in this fluid, by employing rather less dilute sulphuric acid, and at the same time adding a little nitric acid, by which the conducting power of the solution is materially increased. A solution formed by a saturated solution of sulphate of copper, diluted with one-third its bulk of dilute sulphuric acid as before, and to which two drachms of strong nitric acid are added, in the pint of fluid, forms a most unexceptionable solution for general purposes. The lateral growth of the copper in this solution takes place to a great extent, a property which always enhances the value of the process. The nitric acid attacks the positive pole, so that the metallic solution is apt to become stronger. When this takes place, the solution must be diluted. The positive pole is more apt to be attacked after the action has continued some little time, for nitrous acid is formed, which assists the solution. In both these cases, the reduction takes place with considerable rapidity. The effect of the acids is to diminish the resistance offered to the passage of the electric current, which is virtually equivalent to increasing the intensity; and we find that the quality of the copper obtained by either of these methods is the same, being soft, flexible, malleable, and ductile, but not very elastic. To obtain these qualities in the most eminent degree, the voltaic power should be so regulated to the strength of the solution, that a little more would cause the evolution of a few bubbles of hydrogen. We generally require the copper to be somewhat harder, and more elastic than this; to accomplish which, we slightly increase the strength of the solution.

The acid solution must not be employed when the negative plate, or mould, to be copied consists of a more oxydable metal than copper; for the acid would act upon it, and perhaps even entirely dissolve it. In this case, a neutral solution must be used. If in these cases the copper is required to possess the qualities which I have before described, a series of two, three, four, or more batteries must

be used if a strong solution be employed, by which means intensity is obtained, and the tendency to the evolution of the gas is increased. The cost would be, at the same time, double, treble, or quadruple that attending the application of one battery. A flexible state can be, also obtained by using a dilute neutral solution, with a single battery, or even by employing a stronger solution kept at an elevated temperature. The student will now begin to perceive the value of the grand principle — the regulation of the amount of electricity to the strength of the metallic solution.

We can obtain the copper of the utmost possible hardness, though slightly brittle, if we are desirous of employing it in that state, by adopting a somewhat different arrangement; we employ a saturated solution of sulphate of copper, without any acid, a very large positive pole, and we use a cell of such a size that a considerable quantity of electricity is generated. In this case the copper will be found extremely hard, and somewhat crystalline in its appearance. This state may be termed the greater crystalline, and the brittleness depends upon the crystals which form its strucure, as a mechanical dissection will show; for if a piece of this copper be broken, a slight adhesion only will exist between the different particles of the copper. When we throw down the copper, however, in this state, it is apt sometimes to play curious freaks; for the reduced metal, appearing to be abundant, passes to the back of the plate, causing nearly as much deposit behind as before. Sometimes it will pass to the corner, producing efflorescences apparently from a similar cause.

From the preceding statement it is apparent, that it is quite a vulgar error to suppose that the brittleness or flexibility, the hardness or softness, of the copper, depends alone upon the greater or less quantity of electricity passing, or, in other words, upon the rapidity of the process, for a plate may be a fortnight in its precipitation, and yet

so brittle as to break with the slightest touch; and again, when the process has been performed in two days, or even twenty-four hours, the metal has exhibited great flexibility. We may reverse these results by altering the circumstances; thus, a plate may be a fortnight in the making, and by using a weak solution and a slight current, be yet flexible; or it may be made in two days, and still brittle, by using too small a quantity in a very strong solution. The flexibility depends upon the quantity of electricity being suited to the facility with which the reduction of the metal from any solution is effected, and upon the quantity of salt contained in the solution; thus, with a neutral solution of sulphate of copper alone, in order to obtain a flexible and soft plate, a small quantity of electricity must be employed, and that with a weak solution, if it be attached to only one cell of the battery; a stronger solution may be used with a series of batteries with the same result. If the solution be very acid, a more considerable quantity of electricity of a single cell will pass, therefore more sulphate of copper may be employed with the same result, agreeably to the laws regulating the precipitation.

Extreme brittleness may be produced by using a deficient quantity of electricity in a strong solution. In fact, the plate looks as if it were nothing but an agglomeration of bright metallic sand, the particles having no greater cohesion than those of common sand-stone. This state may be called the lesser crystalline.

The copper may be always thrown down as a black powder, a spongy or sandy deposit, by employing a very powerful battery, or by the other general methods stated in the description of the laws. The sandy deposit, arising from too much electricity, must not be confounded with that from too little. They are, indeed, easily distinguished: the former always containing more or less traces of the darker spongy deposit; while the latter possesses a metallic brilliancy; either of them are equally brittle.

The nitrate of copper is a salt far more easily decomposed than the sulphate. It is an expensive salt, out of all proportion to the trouble of preparing it. In the form of apparatus, however, where the solution is kept at the same strength by the aid of a copper positive plate, the first expense is the only one incurred. The electro-metallurgist may readily prepare this salt for himself by dissolving metallic copper in nitric acid. The operator must be careful not to expose himself to the nitrous fumes which are then generated, as by inhaling them, the pulse would be lowered, and other disagreeable consequences produced. It may be acidulated with nitric acid, which will increase its conducting power materially, so much so that scarcely any impediment will be offered to the current of a single pair of plates when a copper positive pole is employed.

There is one objection to the use of nitrate of copper, for the hydrogen not only reduces the copper, but is enabled to decompose the nitric acid. This does not indeed occur when the acid remains as nitric acid to any great extent, but as soon as a little of it is decomposed and nitrous acid set free, it is apt to form little bubbles of deutoxyde of nitrogen on the negative plate, which remain adherent to it, and finally become encased with copper. A plate of copper will sometimes be completely cellular from this cause, appearing like a sieve when held between the eye and the source of light.

When this solution is employed, a pound of the salt may be dissolved in a pint and a half of water, and acidulated with half an ounce of strong nitric acid. From a saturated and acidulated solution of this salt, we can obtain a copper plate in the most rapid manner possible. The positive copper pole should be of the same size as that of the negative plate, and the two poles should be placed within half an inch of each other. A series of from four to six batteries must be employed at ordinary temperatures, though at high temperatures less would suffice. A plate of copper should never be

made by the compound battery process however, unless it be wanted in a great hurry, for although the copper is the same in quality, or even slightly superior to that obtained by a single cell, yet the expense attending its precipitation is greater.

For all the ordinary purposes for which the reduction of copper is required, there is no objection to the use of a small quantity of the nitrate in the solution, and indeed such should always be employed. There is no solution from which good copper may be obtained more readily than the sulphate to which a little of the nitrate has been added. For this reason I have mentioned the use of the nitric acid in the solution, when treating of the sulphate, and be it remembered that if the nitrate of copper is small in quantity relatively to that of the sulphate in any solution, the bubbles of deutoxide of nitrogen, which alone prevent the universal adoption of that salt, never occur.

The muriate of copper may be employed, but I do not know that any advantage attends its application. It is not so readily decomposed as the nitrate, but more readily than the sulphate. From my own experience it is one of the worst solutions for the reduction of copper, as the metal is apt to assume a very peculiar appearance. From this peculiar deposition of copper the presence of muriatic acid had better be prohibited, and, therefore, we should never add it to our solutions of copper. In the employment of the single-cell apparatus muriatic acid should never for the same cause be employed even at the outer or zinc side, for we must recollect that almost all diaphragms allow a tolerably easy passage of the liquid from one vessel to the other.

Other salts may be used, as the ammoniuret, acetate, and hypo-sulphite; these salts offer no advantage, when copper or any other metal of less affinity for oxygen is used for the negative plate; yet, with metals having a greater affinity for oxygen, they may be employed with advantage, for it is

important that the negative metal of itself should exert no action upon the saline solution, otherwise the duplicate will be impaired.

Acetate of copper is formed by digesting common verdigris in acetic acid, and evaporating the product till crystals are obtained. It is a salt difficult to decompose, requiring the intensity of several cells. It is not decomposed by iron whilst neutral.

The compounds which ammonia forms with the salts of copper, are the ammoniuret of the oxyde, the ammonio-nitrate, and ammonio-sulphate of that metal; the reduction of the metal from these is attended with difficulties, and it is requisite that the solution be alkaline from the presence of free ammonia. Iron and steel do not spontaneously decompose these compounds, but I am afraid that this, the only benefit attending their application, will not compensate for the trouble and difficulty attendant on the process. The last salts require a series of batteries to effect their decomposition, although a positive copper pole be used.

The oxyde of copper is very soluble in the muriate of ammonia, but it forms a very bad solution for the precipitation of the reguline metal, as hydrogen seems to have a great tendency to be evolved in it. Cupreous sponge is best obtained from this salt.

We cannot employ a solution of iodide of copper in hydriodate of potash, for iodine is continually being set free if iodide of potassium be added to a soluble salt of copper. Repeated washings of the precipitate will not help us.

The sulpho-cyanide of copper I have tried, but do not like it for electro-metallurgy. The solution in sulpho-cyanide of potassium does not contain much metal. A copper positive pole is but feebly acted upon in it.

The cupro-cyanuret of potassium is another salt, which has yet to be described. It may be formed by boiling the oxyde in cyanuret of potassium, or by making a sheet of copper a

positive pole in a solution of the cyanuret of potassium. The salt when evaporated forms small white crystals; the solution is not a very ready conductor, but may be improved by the addition of free cyanuret of potassium. The only possible advantage it possesses for electro-metallurgy is its non-decomposition by iron, though very fair reguline metal may be reduced from it by either of the battery processes.

Sulphate of copper forms a great many double salts; thus, we have a sulphate of copper and potash, sulphate of copper and magnesia; and there are a great variety of other double salts, as it forms compounds with almost all the alkalies, earths, and even some of the metallic oxydes. From the electro-chemical decomposition of these nothing has turned-up beneficial to the electro-metallurgist, and a great number of them when submitted to experiment were decomposed by iron.

The compounds of oxyde of copper with vegetable acids offer no advantage. The citrate might be used, as it is soluble, and a copper pole dissolves in the liquid; but iron reduces it, so that, being but an imperfect conductor, although otherwise an excellent solution for the reduction of copper in the reguline state, it is never likely to be employed.

The tartrate of copper forms rather an insoluble salt, and the potassio-tartrate cannot be turned to any good account, from the very slight action that the copper pole undergoes in the solution.

There are even many other salts of copper, as the compounds of the oxydes with the acids of fat, &c., but they are insoluble, and there exist, moreover, a great variety of other salts of this metal which water does not dissolve.

As a summary of the modes of proceeding with various solutions of different strengths, it is to be observed, that the more readily any particular salt can be decomposed, the stronger may be the solution; the more difficult of decomposition, the weaker. A more concentrated solution of a salt

requires more intensity and quantity than a weak solution, whilst a weaker solution may have the current of a single battery passed through it. These comprise the whole of the practical secrets for regulating the quality of the copper, and they have materially assisted in the discovery of the general laws which have been already laid down, for in every case the hydrogen is near its evolution when the texture of the copper is at its utmost degree of tenacity.

It has been mentioned that rolled copper may be used as the positive plate of the decomposition cell, as, during the action of the battery, the metal is dissolved to the same extent as it is reduced at the negative plate. It is curious to notice how regularly that part of the plate which is opposite to the negative pole is thinned, until the whole is removed. From the amount of action being greater opposite to the surface receiving the metallic deposit, it happens that when a medal is allowed to remain for some time opposite a piece of copper, during the process, that a circular hole is formed in the positive plate. For this reason, it is advisable so to vary the arrangement of the negative and positive surfaces, that every part of the plate of copper to be dissolved should be equally acted upon; but during this process a considerable quantity of black matter, apparently charcoal, is left, arising from impurities in the manufacture of the copper. The ordinary sheet-copper of the shops appears a compound of copper and carbon, more analogous to steel than to pure copper. This carbon, it acquires in the very curious process called polling, which is performed by allowing willow sticks to be charred by the melted copper, when the metal absorbs a certain portion of the charcoal. The black matter is not always attributable to charcoal, for it appears to a much greater extent in a neutral than in an acid solution; in which case it appears to be partly owing to the formation of an oxyde of the metal. If an electrotype plate be made the positive pole of the apparatus, no remains will be left, but every particle will be

dissolved. The piece of copper forming the positive pole of the trough may be partially dissolved by coating the rest with any varnish or substance which can resist the action of the fluid, a property of which hereafter we shall have more particularly to speak.

The negative pole to receive the reduced copper may consist of a solution of sulphate of copper, plumbago, charcoal, gold, silver, platinum, palladium, nickel, or copper itself, all of these being suitable for the reception of copper. All other metals are, more or less, acted upon by the solution, though lead and its alloys may be used with the sulphate, especially if it be diluted. Tin is much inferior to lead for the reception of this metal, as it acts more readily upon its salts.

The same observations apply to the nitrate of copper, except that lead, tin, and their alloys, much more readily act upon them than upon the sulphate, and that iron does not quite so readily decompose this solution as it does the sulphate. Almost all metals may be employed as the negative pole in the ammoniurets of copper, and also in the cupro-cyanuret of potassium, for they so feebly act upon these solutions as to make it scarcely worth consideration. Iron and even zinc produce but little change upon them.

The copper thus reduced, assumes the form and appearance of the cast on which it is deposited. If the surface of the original be polished, the duplicate will be so likewise, and the colour will, in many cases, be slightly influenced, especially where copper has been used as the original. The surface is not quite so brilliant, where lead, tin, and such metals are employed, but when black lead is applied on smooth surfaces, as sealing wax or white wax, the surface of the duplicates is perfectly bright.

When we desire to clean the surface we can easily effect our object by brushing it over with charcoal and water, or with emery and water, which speedily removes any extra-

neous matter from the surface. It is by no means a good plan, ordinarily, to plunge the metal in acid and water to effect this object, as it acts upon the surface and injures the brilliancy of the metal.

Copper may be reduced by the single-cell process, from a great variety of salts by means of zinc, tin, lead or iron; the first and last, however, being the only metals likely to be employed. The advantages and disadvantages of the single-cell in comparison with the battery apparatus, have been fully discussed in the first chapter of the second book; but if there is one metal to which the single-cell process is more particularly applicable, it is copper, especially its reduction from the more ordinary salts: where the acid in conjunction with the metal is not worth preserving, the employment of the zinc single-cell apparatus, unless under particular circumstances, is better dispensed with. The reduction of the metal by iron, is for its economy to be preferred to all other methods in those cases where it is applicable. Yet upon the whole, as the single battery process is suitable to every possible case, for which the reduction of copper can be required, it as a general rule must still supersede the other modes of working in copper. The expense of each process has already been noticed when treating of the general means by which the expense of working in metals is calculated, and as the reduction of copper is there taken as an example, it would be but a vain repetition again to detail it.

For copies of medals, and other works of art, a copper surface is not always desirable, bronze having a much better appearance, and this may be communicated in various ways. The one most generally adopted is the following:—The medal is covered over with oxyde of iron, and placed in a muffle, and in this state exposed to heat; when removed from the fire, it simply requires to be brushed, and is then fit for the cabinet.

Generally, however, we adopt more ready methods of pro-

ducing the bronze; one of which is to brush the medal over with black lead, immediately upon its removal from the solution. It is then placed on the fire till moderately heated, when it may be smartly brushed with a hog's-bristle painting-brush, the slightest moisture being used at the same time, in order to remove the black lead. An uniform shining bronze is thus obtained. There is no method of bronzing to be preferred to this for beauty, as a medal not two hours old displays the fine colour of antiquity so much prized by numismatists. In these operations, I believe an oxyde of copper is produced, to which the effect is mainly to be attributed. If the metal has been allowed to remain out of the solution for some time before the bronze is given, it is not found to take so readily. In that case it is better most thoroughly to clean the surface, and then to proceed as before.

The application of a very minute quantity of grease, or wax, much improves the bronze. This is, however, unnecessary when the copper has been deposited on a mould consisting in part, or entirely, of these substances; but in other cases the application is very advantageous. Grease or wax alone, when applied in an infinitesimal quantity over the surface of a medal, enables it to take a fine bronze when simply heated to a proper temperature. We cannot readily give the precise temperature at which the best effect is produced, but, as a general rule, the heat should be applied just so high, and for such a length of time, that smoke from the incipient decomposition of the grease begins to appear. A greater heat causes the copper to blister, but if removed at that precise moment the surface will be beautifully oxydated. The perfection of this kind of bronzing, as well as that of the black-lead, depends in great measure on the skill of the operator, and the effect may be much enhanced by rubbing the medal with a nail-brush containing plenty of bristles, and finishing it with a little whiting, placed on a piece of wash-leather.

The French have a method of bronzing clichées, which is very effective. They are sometimes so readily mistaken for copper, that a gentleman placed what he conceived to be a copper medal into a trough to obtain a reverse, when to his astonishment, on the removal of the mould, instead of a copper medal he found he had a leaden one. The mode by which this bronze appearance is given, is to moisten the surface with a little spirits of wine, and at the moment of drying, dusting it with a little red chalk, modified in colour with a portion of black-lead, and then with a good puff dispersing any superfluity that may have been employed. This process might also be employed for copper medals, but the colour is, perhaps, not so fine as by the process already detailed. There are other modes of bronzing clichées which are not applicable to copper, such as dipping them in a solution of the binacetate of copper, acidulated with acetic acid, by which means the medal reduces a small portion of copper, and therefore has all the appearance of a copper medal.

Instrument-makers have a mode of bronzing the copper which is used for binding-screws and other parts of their apparatus. It is simple and effectual, for the metal is simply to be rubbed over with a little weak solution of platinum, when the copper, or a portion of it, is dissolved, and an equivalent proportion of platinum is thrown down. They generally protect this from change by varnish, but this should never be applied to delicate impressions. A solution of gold would answer the same purpose, did not its value prohibit its application.

Another valuable method of bronzing is the application to the metal of a very weak solution of the hydro-sulphate of ammonia, or the sulphuret of potassium, when a sulphuret of the metal is obtained, which is of a very beautiful colour. If the solutions are used too strong, a thick layer of sulphuret is produced, which much detracts from the beauty of the medal, as a work of art.

The object of all these methods is to throw up the fine workmanship—a result which is efficiently obtained in the colour given by the methods which have been detailed; the choice of these is left to the operator, but perhaps none excels, or even equals, the mode of bronzing by black lead, or grease, when those operations are performed with care, and in the manner which has been described.

(178.) Zinc may be reduced in the bright metallic state from a variety of solutions, as the oxyde of zinc is soluble in a great number of acids. The sulphate of zinc, however, is by far the most common salt of this metal, and it is formed tolerably pure and in large quantities during the employment of galvanic batteries. The solution of the sulphate of zinc may be of any strength, but perhaps the stronger is to be preferred. It should be as neutral as possible, and it is a good plan to add a little oxyde of zinc to the sulphate, but this salt always reddens litmus paper. Sulphate of zinc is best formed for electro-metallurgy in a series of my galvanic batteries, gradually decreasing the rapidity of the process towards the termination until zinc begins to be deposited. Zinc can only be reduced practically by the battery process. In the trough it is as well to use a very large zinc positive pole, and take especial care to cause a proper diffusion of the new sulphate of zinc. Hydrogen has a considerable tendency to be evolved from the solution. The battery should be small as the galvanic power should be feeble, and the resistance in this case should be rather in the battery or the connections than in the positive pole. Reduced zinc may be thrown down in a very flexible state, and is far more slowly acted upon in dilute sulphuric acid than common zinc.

The ammonio-sulphate of zinc may be made by adding liquor ammoniæ to a solution of sulphate of zinc. It is a good conductor, and may be used with a zinc positive pole. It is a tolerably good solution of the metal to obtain the reguline deposit.

Potash added to a solution of sulphate of zinc throws down a precipitate which is soluble in excess. The zinc is not so readily reduced from it as from the sulphate, and it requires a series to effect that object. The zinc positive pole does not freely dissolve in it.

The chloride of zinc is usually formed by dissolving the metal in muriatic acid, when hydrogen is most abundantly evolved. It is now occasionally used in surgery as an escharotic, and it may be employed for electro-metallurgy in the same way as the sulphate of zinc. It is a good solution, but possesses no particular advantages. If chloride of zinc is formed by the galvanic battery, it is better adapted for electro-metallurgy. This, perhaps, is the best solution for obtaining crystals of zinc.

The nitrate of zinc formed by the action of nitric acid on zinc is the very worst salt I have tried for the reduction of the metal in the reguline state.

The oxyde of zinc is very soluble in muriate of ammonia. There is a great tendency to the evolution of hydrogen in this solution, and therefore it is not a good compound for the reduction of the reguline metal, though it is well adapted for obtaining zinc sponge in large quantities.

The acetate of zinc may be formed by digesting oxyde of zinc in pyroligneous acid, or by making zinc the positive pole in that fluid. It is a very good solution for obtaining reguline metal by the single battery process.

The tartrate of zinc formed as the acetate, possesses no peculiar advantage for electro-metallurgy.

The potassio-tartrate of zinc may be made by boiling the oxyde in cream of tartar, or by making a plate of zinc the positive pole in a solution of bitartrate of potash. The zinc positive pole does not freely dissolve in it.

The hydriodate of zinc is a good solution for electro-metallurgy. It is best formed by galvanism, by using a zinc positive pole in a solution containing a very minute quantity

of iodide of potassium and a very large quantity of undissolved iodine at the bottom of the vessel. The iodine will at last be entirely taken up and a corresponding quantity of iodide of zinc formed.

The zinco-cyanuret of potassium may be formed by either digesting the oxyde in the cyanuret of potassium, or galvanizing a plate of zinc in a solution of the cyanuret. It forms octohedral crystals, but it is a difficult salt to decompose, requiring a series of batteries for its reduction, and it is difficult to obtain even a small amount of zinc from it.

The reduction of the zinc is not of much importance in itself, although very interesting when considered in reference to the plates of galvanic batteries; for if one battery in a compound series, from any cause, has the whole of its exciting fluid neutralized, then will that cell be in the same condition as the apparatus employed for the reduction of the zinc, and zinc will immediately be deposited on its negative pole. This will occur with all the forms of batteries now employed, although it is a property of no consequence, as the action of the battery ought to be stopped before it has so thoroughly exhausted itself. When this deposit takes place, it can readily be removed by placing the plate in contact with any metal which can act as a negative plate to it. The necessity of this arises from the difficulty with which pure zinc is dissolved in acid. As soon as a dozen or more batteries, arranged as a series, have the acid of their exciting fluid saturated with zinc, the zinc will be deposited on the negative plate, if a single battery only out of the whole number contain any acid; thus eleven batteries out of twelve may have their negative metal thickly coated with a very beautiful and perfect deposit of zinc, whilst the last will not have the smallest trace upon it. Zinc is never found in all the batteries of a series. There will be some curious matter to be discussed when we have to describe the reduction of alloys.

In the reduction of zinc from any salt there is a difficulty

to be encountered which will be explained when treating of the reduction of alloys, for reguline zinc of the best quality may go down at first, but afterwards one of the varieties of the spongy deposits will take place. This alone forms a great impediment to the reduction of zinc on a large scale.

The reduction of zinc is generally a disadvantageous process, as the cost of its deposition is the same as that of copper, from their voltaic equivalents being alike. Zinc, however, is worth but threepence a pound, whilst the value of copper is a shilling.

(179.) Cadmium has a variety of soluble salts, of which the sulphate, ammonio-sulphate, and chloride, are the only ones I shall notice. The sulphate may be employed with a cadmium positive pole and a small battery. For small negative surfaces, one of the odds-and-ends' little glass batteries described when treating of the reduction of platinum is well adapted. Cadmium of good quality does not readily go down from the sulphate.

The chloride of cadmium may be made by galvanism, by arranging a piece of cadmium as the positive pole in dilute muriatic acid. The chloride of cadmium behaves much in the same way as the sulphate. Cadmium, however, has a tendency to be thrown down in a peculiar state between the sponge and crystalline deposits, and hydrogen has a considerable tendency to be evolved from both this and the last solution.

The ammonio-sulphate of cadmium may be formed by adding ammonia to a solution of the sulphate, as the precipitate is soluble in very small excess of the precipitant. It may be employed with a cadmium positive pole in conjunction with a small odds-and-ends' battery. This is the best solution for obtaining the reguline deposit, which may be easily thrown down in a flexible state from it.

The reduction of cadmium might be followed with advantage as an equivalent of power, value $\frac{1}{20}$ of a penny would

reduce about 56 grains of the metal, so that a pound of cadmium obtained by the voltaic force would only require about sixpence to be added to the cost of the metal, which, being scarce, is considerable.

(180.) The salts of iron have a strong tendency to be peroxydised, in which state they cannot be reduced by the voltaic current. We must use, therefore, the proto-salts of which the proto-sulphate of iron is a good example; this is prepared very carefully for the use of chemists, and the reduction of metallic iron may take place from a solution of their proto-sulphate. The metal upon which the deposit is to be effected, is connected with the zinc of the battery, whilst an iron nail is connected with the silver; as the source of power, a relatively small single battery will suffice, and the silver need not be larger than the negative pole in the trough. The nail is to be just so far dipped into the solution, that the minutest quantity of hydrogen, or none at all, is evolved from the metal to receive the iron; and after the lapse of a short time, the negative metal will become coated with metallic iron. The reduced metal is brighter, and rather whiter than polished steel, but it soon tarnishes in the air.

Proto-chloride of iron may be formed by dissolving iron in muriatic acid; it forms a perfectly neutral salt, and is well adapted for the reduction of the metal. It may be reduced by either battery process, of which the single battery will always suffice. The hydrogen has not so great a tendency to be evolved as in the sulphate, and the metal goes down freely from it. This is an excellent solution, perhaps the best for the reduction of this metal. If the iron is removed from the plate on which it is deposited, the surface next to the negative pole is polished if the original is so also; and very thin layers of this metal have a very fair cohesion, inferior, however, to the rolled iron of commerce.

Iron may be reduced, but only in the minutest quantity, from the ferro-cyanate of potash, which is, therefore, useless for electro-metallurgy.

The compounds of iron with the vegetable acids may be employed for electro-metallurgy. The citrate may be made by arranging a plate of iron as the positive pole in a solution of citric acid; but it is difficult of decomposition, requiring a series of batteries.

The proto-ioduret of iron as used in medicine may be employed for electro-metallurgy. It is not, however, so good a compound as the chloride for these purposes.

Iron reduced by electricity has not yet been examined as to its magnetic properties, and, doubtless, pure iron obtained in this manner must possess peculiar properties still undiscovered.

The reduction of iron in a pecuniary point of view is the very worst process in the whole range of electro-metallurgy; for the metal is worth scarcely anything in comparison with others we have had to treat of. The iron-masters, doubtless, will sleep in perfect security when they are told, that for one equivalent of galvanic power derived from my battery costing $\frac{1}{20}$ of a penny, but 28 grains of iron are reduced; so that the reduction of 1lb. of iron, worth about one penny, would cost more than one shilling for the bare materials used in its reduction, to be added to the value of the metal. Under this aspect of affairs, not only the blast, but even the puddling and melting furnaces, are likely to continue to send forth their pestiferous fumes by day, and their pandemonium-looking flames by night, corrupting the atmosphere to the injury of vegetation, as well as to the detriment of the health of all living beings.

(181.) Tin is a difficult metal to manage, because the transition from the decidedly spongy state to the crystalline is so rapid, that we can scarcely hope to obtain any amount of reguline metal. The salts which I have tried are numerous, but they all have the same general characters. The muriate is the most common of the salts of tin. It yields very fine crystals when decomposed by a small odds-and-ends' battery, with a tin positive pole. If the battery is very active, the

tin positive pole large, and the solution strong, the growth is marvellous; a little point will present itself on the negative metal, which rapidly increases, and in a few seconds will grow to the positive pole. If during this rapid growth the positive pole be moved the crystal will follow it.

The finest crystals are obtained, however, by the strongest neutral metallic solution, and a very low action in the battery. The deposit is certainly very beautiful. The spongy deposit of tin is very peculiar, and the electro-metallurgist is apt to see it much oftener than he wishes; for that light, flocculent, spongy deposit, which is frequently observed during the action of the battery, is nothing but metallic tin, arising from zinc clippings mixed with solder being melted with the rough spelter; if a little of this mass be squeezed between the fingers into a mass, and then struck and rubbed against anything hard, a bright metallic surface will be exposed.

The sulphate of tin may be formed by digesting the protoxyde in dilute sulphuric acid; it is rather a better salt than the other; and might be used for some purposes to coat iron. A kind of lesser crystalline deposit may be obtained from it, but not sufficiently good to form a tin medal.

The oxalate of tin and acetate of tin are made in the same way as the sulphate. They are not quite such good conductors as the sulphate, and do not yield good reguline tin to any extent.

The potassa solution of the oxyde of tin is a bad conductor, requiring an intense battery for its decomposition. A good thin layer may be deposited from the solution, but I have never made a medal with it.

The oxyde of tin dissolved in cyanide of potassium is difficult of decomposition, and does not yield any amount of tin.

I have tried a great variety of other mixtures of these salts, as oxyde of tin with cream of tartar, sulphate of alumina, chloride of sodium, hydriodate of potash, &c., &c., without any satisfactory result.

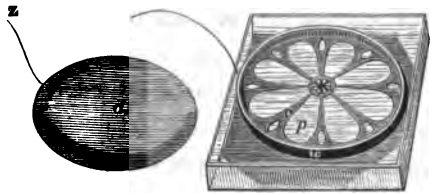
The reduction of tin by galvanism cannot be considered an advantageous process, from the low value of the metal. One equivalent of power, costing $\frac{1}{20}$th of a penny, will reduce about 58 grains of tin, making the cost of the power about sixpence a pound to be added to the value of the tin.

(182.) Lead has but few soluble salts, of which the acetate, the nitrate, and plumbo-cyanide are the principal which deserve attention.

The acetate is abundantly soluble, and may be employed for the reduction of the metal. It may be used with a lead positive pole, connected with a small battery. Lead has such a tendency to be deposited in crystals from this solution, and the crystals grow so rapidly, and to such a size, that it is in vain to attempt to obtain the reguline deposit from it, especially as the gradation from the spongy to the reguline deposit is very close. The crystals of lead as reduced by zinc form what is termed the lead tree. To produce it a small piece of zinc is suspended in a bottle, containing a clear solution of acetate of lead, when speedily the metal begins to be thrown down, and continues to be deposited in the beautiful forms to which the name of the lead-tree is given. The experiment may be varied by using a copper wire round the zinc, and passing it to the bottom of the vessel, when the lead will also be deposited on the copper wire; in a solution of acetate of lead, the positive pole, becomes incrusted with a deposit, which is the peroxyde of that metal. I have observed a similar deposit in the decomposition of other metallic salts, but as none have been turned to any account but this, the fact need not be more particularly alluded to. The production of this oxyde has been used by Mr. Gassiot to form metallo-chromes, which for striking effect and beauty of colours are unequalled by any other work of art. They are formed by throwing down a deposit of this compound of various thicknesses on a plate of polished metal (burnished steel answering best). The difference in the thickness of this

deposit is accomplished by placing the plate of steel at unequal distances from the negative pole. The negative pole should consist of a copper disc made slightly convex, which at once very effectually causes a variation in the distances. The exact *modus operandi*, which Mr. Gassiot recommends, is to place the polished steel plate (p), in a solution of acetate of lead, and over that a piece of card with some regular device cut out (c). A small rim of wood (w) should be placed over the card and the circular copper disc (d), (which is represented in the wood-cut on one side), over all. On contact being made from 5 to 20°, with 2 or 3 cells of a small battery—the steel plate being connected with the silver, the copper disc with the zinc, the deposit will be effected, and a series of those exquisite colours will delight the operator, which arise from the decomposition of light, by a layer of different thicknesses of peroxyde. By reflected light every prismatic colour is seen, and by transmitting light a series of prismatic colours complimentary to the first series will appear occupying the place of the former series.

Fig. 26.



The best way of viewing these beautiful fairy forms is to place the plate before a window, and incline a sheet of white paper at an angle of 45° over the plate, when if the plate be viewed at a considerable angle the colours appear to stand boldly forth on a white ground.*

The tris nitrate of lead forms rather a better salt for the reduction of reguline metal. It may be used in the same

* I have formed metallo-chromes analogous to those described in the text, in a very different way, yet dependent on the same principle. A plate of polished copper placed over a card device, and then exposed to iodine, becomes coated with a thin film of apparently iodide of copper, which shows the prismatic colours very beautifully; yet far inferior to those formed by peroxyde of lead. This experiment may be varied in many ways.

2 A

way as the acetate, but I have only reduced small portions of reguline lead that I could strip from the negative pole from it.

From the plumbo-cyanide of potassium I have reduced reguline lead of good quality, which could be stripped from the negative plate, still only in small quantities; probably, from the insolubility of the oxyde of that metal at the positive pole.

The reduction of lead by galvanism is not, independently of the difficulties attending it, a good process, because the value of the metal is low, yet inasmuch as we obtain for one equivalent of power 104 grains of lead, that would rather lessen the cost of the process.

(183.) Antimony is one of those metals by no means deserving more than a cursory glance. The only solution which I shall notice is that of the potassio-tartrate. It is tolerably well adapted for the reduction of the metal in the reguline state. It is not very readily decomposed, requiring a couple of batteries with an antimony positive pole. The metal is then thrown down slowly, but forms a brilliant deposit, which may be stripped from the negative pole. Antimony instead of being deposited at the negative plate, in some cases combines with the hydrogen, and is evolved as antimoniuretted-hydrogen gas.

(184.) Bismuth is another metal, to the characters of which, in an electro-metallurgical view, very little interest can be attached. Its super-nitrate is a soluble salt, and may be employed with a positive pole of the same metal attached to a single battery. The deposit, however, from this solution has a tendency to assume a mixture of the sponge and crystalline deposits.

The tris nitrate, or medicinal salt of bismuth, is an insoluble salt, and therefore inapplicable for our purpose.

The iodide of bismuth is soluble in excess of iodide of potassium, but I have not turned it to any good account.

The potassio-tartrate of bismuth may be soluble by making a piece of bismuth the positive pole in bi-tartrate of potash. It may be employed with two batteries arranged as a series. It is not a ready conductor. The metal is reduced but slowly

from it. A white powder forms upon the positive electrode, which at length stops the action. So little importance is attached to the reduction of this metal in the reguline state, that I have not bestowed much time upon it.

(185.) Uranium is another metal which I have endeavoured to deposit from its nitrate but without success; in fact, being a proto salt it was not likely to be reduced. I have not succeeded in procuring any proto salts of uranium on which to experiment.

(186.) Arsenic is a metal not likely to be of much value for electro-metallurgy, yet there are some important circumstances to be noticed in its characters when subjected to the voltaic fluid, which require some notice in this place.

The oxide of arsenic or arsenious acid is frequently employed as a means of destroying animal life, and though its means of detection when improperly administered, are more simple and certain than that of any other poison whatever, the minds of chemists are continually being directed to some new mode of effecting that object. As far as the voltaic power may be brought to bear in the detection of this metal, I shall briefly notice the subject, but no further.

Arsenious acid is not very soluble in water, and is but a bad conductor of the voltaic force. It may be decomposed by a series of batteries with platinum electrodes, oxygen being evolved at the positive, and the metal reduced at the negative electrode. The hydrogen, however, in this case, not only reduces a part of the metal, but combines with another part, forming arseniuretted-hydrogen gas. This gas has a peculiar alliaceous or garlicky smell, which is a good characteristic of its presence. If a small jet is inflamed and a cold object placed over it, arsenious acid is deposited, but, however, if the cold object be depressed so as to cut a portion of the flame, metallic arsenic will be reduced.

The phenomena appertaining to this gas were first applied ingeniously by Marsh to the detection of arsenic. He employed zinc, dilute sulphuric acid, and the suspected liquor,

and then tested the hydrogen when inflamed, in the manner just pointed out. He describes a considerable number of pretty contrivances for effecting that object; sometimes he uses a tube simply bent upon itself into one end of which a stop-cock and jet is fixed, the other being left free; sometimes he dilates his tubes into a bulb. A great variety of apparatuses are described for the production of the gas. All these forms are well adapted for the detection of arsenic when they are not wanted for organic mixtures, but when the contents of the stomach have to be examined, they are generally but ill adapted from the froth that generally ensues. When arsenic is taken into the stomach, that organ not liking its new customer endeavours to remove him out of contact by pouring out a large quantity of mucus which envelopes the poison and protects the stomach in some degree from its influence. The cunning chemist should mechanically dissect from this secretion the white powder, and subject that to experiment, for it is only in those cases where poisoning is effected by very minute quantities, that the poison is not at once seen as a white powder. Having separated it, it is to be dried at a gentle heat, and distilled from the bottom to the upper part of a test tube by means of a spirit lamp when it is ready for the various experiments to which the operator is inclined to submit it. If we choose the arseniuretted-hydrogen test the vessel should be capacious, a phial with a piece of glass tube drawn to a point and inserted in the cork, is well adapted.

Fig. 27.

Zinc is apt to contain arsenic itself, therefore it would be better always in judicial cases to employ that reduced by the voltaic agent; the sulphuric acid is also apt to be intermixed with small portions of this metal, for which reason both should be tested before they are used. We should never be satisfied with this test alone, unless we can obtain arsenious acid sufficient to test with the am-

monio-nitrate of silver, ammonio-sulphate of copper, and sulphuretted-hydrogen, for not only may a little black crust of antimony be mistaken for arsenic, but even a little animal matter may give a similar deposit.

Morton, in order to overcome the errors from impurities in the acid and zinc, proposed to subject the suspected fluid to an intense galvanic battery, and then examine the hydrogen. The only difficulty in this proceeding is the imperfect conducting character of the compound to be operated on. This difficulty might be overcome by the addition of pure potash.

I have now to call attention to the following mode of taking advantage of the opportunity afforded to us of subjecting the suspected fluid to a long continued galvanic current of but feeble quantity; for by that means we should be enabled to determine the presence of arsenic, by heating the negative pole in a test tube, when arsenious acid would be formed. This would be deposited at the upper part of the tube, and on being tested would give the most unequivocal signs of the presence of that metal. This although by no means the most delicate is by far the most satisfactory proceeding we can adopt, for we need not introduce into the suspected solution, any new substance, so that not a shadow of doubt could be thrown on the accuracy of the result if arsenic be obtained: if, however, we do not succeed in obtaining arsenic, it is not an infallible proof of its absence. By this plan the following characteristics are shown:

(*a.*) The reduction of the metallic arsenic on platinum.

(*b.*) Its volatility and conversion into arsenious acid, leaving the platinum clear.

(*c.*) The yellow precipitate of arsenite of silver with ammonio-nitrate of silver.

(*d.*) The green precipitate of arsenite of copper with ammonio-sulphate of copper.

(*e.*) The yellow sulphuret of arsenic with sulphuretted-hydrogen.

In conducting the process, a series of not less than a dozen batteries should be used, and the process should be continued till the negative platinum pole (a wire will suffice) becomes coated with metallic arsenic which presents a somewhat bright black appearance. The wire is then simply to be coiled up, placed in a test tube, and heated over a spirit-lamp when the arsenious acid will be seen at the upper part of the tube, as small white crystals, which are to be dissolved and subjected to the other solutions. By continuing this process sufficiently long, the whole or the greater part of the arsenic will be reduced, and then would the medical man be enabled to go into court armed not only with the reasons in his breast, but the arsenic in his hand.

If a copper or a silver positive pole be used in a solution containing arsenious acid, the yellow or green precipitate will be formed; but they are not satisfactory modes of detecting the presence of that metal.

(187.) I have endeavoured to reduce tungsten from tungstic acid by using a small platinum wire as a positive pole in the solution of the acid. It is but an imperfect conductor, and requires a series of nine or ten batteries. I have not, however, succeeded in obtaining any metal from the acid.

(188.) Cobalt may be reduced from its chloride, to which excess of ammonia has been added, by using a cobalt positive pole connected with a series of batteries, when the deposition will take place upon the negative plate, which may consist of copper. The reduced metal is white, but it is not thrown down freely. The chloride of cobalt alone, seems only to yield an oxyde at the negative pole. The cobalto-cyanuret of potassium formed by digesting oxyde of cobalt in the cyanuret, yields by decomposition with a compound battery some metal, but hydrogen has a great tendency to be evolved from this solution.

(189.) Manganese has been attempted to be reduced from the sulphate or chloride with signal failure, for the hydrogen has a decided preference to be evolved, even from a polished

surface, than to reduce the metal. At the positive pole an iridescent deposit, apparently a peroxyde, is abundantly thrown down.

(190.) Hitherto we have only considered in this chapter the formation of single salts, and the reduction of simple metals. We have now to discuss the important question, whether two or more metals can be reduced at the same time; and whether the metals can be thrown down conjointly with other bodies. This, considering the amazing number of solutions, becomes a very complex question; and only a general outline of the principles regulating these phenomena can, in the present state of our knowledge, be attempted. In entering upon this subject, I began by selecting metals far apart in the facility of their reduction by hydrogen; thus, solutions of the salts of zinc and copper, being mixed, only copper was reduced at the negative pole. Without detailing a mass of similar experiments, I shall at once state as a fundamental principle, an absolute law derived from a most extensive examination of the voltaic force, that **the voltaic circuit is invariably completed in that mode which offers least resistance to the passage of the force.** That is to say, that if a great variety of roads are offered by which that object may be effected, that the force, provided the road be large enough, would pass exclusively through the one offering the least resistance. To take an example of this, add to strong nitric acid,—chloride of gold, chloride of platinum, chloride of palladium, and any other metallic salt you have at hand that will remain soluble in the acid; and then decompose the mixture between platinum poles, you will find that the circuit will be completed alone through the nitric acid. You may analyze your experiment by placing each salt in a separate vessel, with precisely the same result, as the current will alone traverse the fluid easiest of decomposition, provided that the electrodes exposed to that fluid be sufficiently large. By acting upon this principle the student will perceive that one body

might be separated from another, or even from a variety of others; thus if brass is dissolved in dilute sulphuric acid by the aid of the voltaic force, the precipitate at the negative pole will by management be pure copper only. A person who accidentally stumbled upon this result, bought a large quantity of that alloy in the vain hope of amassing a fortune by what he conceived to be a transmutation of metal, though he doubtless must have discovered at last that he only obtained the copper originally contained in the alloy.

Whatever experiments are detailed relative to the reduction of the alloys, the converse of them applies exactly to the separation of one metal from another. Before we proceed further in our inquiries we should form a list of the fluid roads by which the voltaic circuit may be completed, and place them in the order of the facility with which the passage is made by the voltaic force. As it has been shown that the decomposition of various salts is attributable to the secondary action of hydrogen, termed electro-chemical decomposition, the first thing that we have to determine is the point, in various cases, at which hydrogen would rather be evolved than decompose the metallic salt. But the very construction of my battery depends upon the primitive fact that different metals, and even the same metals under different circumstances, evolve hydrogen from the same solution with various facilities. It is natural to suppose then, if our law for the passage of the fluid be correct, that there are some cases where the nature of the negative plate on which the reduction of the new deposit takes place, influences the result: this is actually found to be the case, for sometimes in the self-same solution, when a smooth negative plate is used, the circuit would rather be completed by reducing a metal, but when a rough plate is employed, by the evolution of the hydrogen. This most interesting fact is in no instance better shown than in a slightly-acidulated solution of sulphate of zinc, from which bright zinc will go freely down on smooth platinum, whilst

from platinized platinum the hydrogen would be evolved. This experiment may be varied a hundred analogous ways, with results at one time in favour of the evolution of the gas, at another of the removal of the gas by the decomposition of some compound. This at once introduces a new element into our reasonings, for we should form a table showing the relative ease with which hydrogen is evolved from various bodies; the top of this table is either platinum, palladium, or silver, in the infinitely divided state used for my battery, but the exact relation which the perfectly divided metals bear to each other, or even to themselves in other states, in different solutions, or even in the same solution, at different temperatures, I am unable at the present time to give; indeed it would be a work of such mechanical labour, that I should not with my present avocations feel warranted in undertaking it.

The evolution of hydrogen gas from any given solution being taken at unity as soon as the ease of its evolution is less than any other mode by which the circuit may be completed, the evolution of the hydrogen is ceded to that mode: generally, the hydrogen if not evolved, reduces some oxygenated body or some metallic salt, and then the analogy is kept up by its reducing that salt, which yields its metal most readily to the gas. The gas is perhaps easiest evolved from muriatic or dilute sulphuric acid.

We here require another extensive table showing the relative ease with which bodies are reduced by hydrogen; perhaps nitric acid is at the top of the list; then follow the salts of some of the nobler metals, whilst salts of zinc and numerous other metals are below the evolution of hydrogen from sulphuric acid.

Nitric acid.	Hydrogen dilute sulphuric acid.
{ Gold chloride.	Cadmium sulphate.
{ Palladium nitrate.	Zinc sulphate.
{ Platinum chloride.	Nickel sulphate.
Silver nitrate.	Iron sulphate.
Copper sulphate.	Manganese sulphate.
Tin sulphate.	Salts of alkalies, generally.

The above is given as a rough specimen of a table showing the relative facility by which the removal of gas may be effected; therefore, supposing our electrodes were sufficiently large, and an ample supply of solutions of the various salts were afforded, but one compound would be decomposed at one time.

However, suppose by using an intense voltaic current we compel such a quantity of the force to pass from a small electrode, that any one compound body in its vicinity is insufficient to complete the circuit, it would then be completed through two, three, four, or more bodies, and it would reduce them all at once; thus, our mixture of metallic salts with nitric acid, decomposed by an intense current with small electrodes, had a great variety of metals reduced, whilst on the increase of the poles the circuit was entirely completed through the nitric acid. In the same way I have decomposed twenty different solutions, arranged not as a series but as one decomposition cell.

As a general principle, to obtain a deposit of two or more bodies on any negative pole, we must use a quantity of the voltaic force, more than sufficient to reduce the elementary substance from the compounds most readily decomposed. By the first law regulating the quality of metal reduced by the voltaic current, the metal is always reduced as a sponge when hydrogen is evolved from the negative plate; therefore, it would be impossible to obtain a reguline alloy in a solution of any two metals, one of which is above the other below the evolution of hydrogen, from the particular negative pole we employ in these solutions.

Such is a rough sketch of the principles to be pursued for the reduction of alloys, but at present practically I have not reduced a perfect reguline alloy of any metal, though I feel no doubt by following out the above principles, a person might succeed in attaining his object with some metals, by a careful examination of their various salts.

The general principle which regulates the reduction of alloys is far more important than for the specific object for which it is given; for the experimenter will find that the current will invariably pass through the road which presents the least obstacle, be that obstacle solid, fluid, elementary, compound, small or great.

(191.) In conducting my experiments on the reduction of alloys, certain phenomena and peculiarities were noticed that have so important a bearing on the theory, or rather the rationale of the voltaic current, that it becomes my duty at once to draw up the curtain and expose the conclusions to which they lead, as a knowledge of them will give to the operator great advantages, and enable him, by rightly understanding the force with which he is working, to conduct his various processes to the best possible advantage.

In these experiments I noticed that in various mixed solutions the quantity of voltaic force passing was not at all dependent on the nature of the negative element, but upon the ease with which the hydrogen was removed from it. Thus in a solution of sulphate of zinc very slightly acidulated the hydrogen could not be evolved from smooth copper, but would rather reduce the sulphate of zinc when connected with a small battery. The substitution of smooth platinum in no way added to the power, but the employment of platinized platinum caused an abundant evolution of gas, even to the removal of the zinc already reduced on the smooth platinum. Any metal having but little affinity for hydrogen caused a similar result; thus, iron caused gas to be evolved and increased the force passing, when smooth platinum would not have the effect, and even zinc itself caused a little gas to be evolved, because the adhesion of the gas to it is slighter than the adhesion to smooth platinum.

In the same way I observed that nitric acid allowed far more electricity to pass than sulphate of copper; and that again, than dilute sulphuric acid, simply from the facility with

which hydrogen reduces these substances being greater than the facility of its evolution. I moreover noticed in other cases that the hydrogen would rather be evolved than reduce a metallic salt,—as sulphate of zinc;—and in every case that the facility of its removal affected the amount of power passing, quite independently of the nature of the negative plate.

Now these facts appeared to me a positive proof of there being no such thing as a negative plate contributing to the production of power, and that this latter is of no value, further than as a means for the removal of the second element of the intervening compound fluid. On the other hand, the multitude of experiments by Faraday all show that the chemical action between one element of a compound fluid and some conducting body appears to be the source of the power, or rather that the power is always dependent on and proportionate to this chemical action. Putting these two series of facts together, an idea presented itself to my mind explanatory of the nature of the voltaic force, for if the force from the experiments of Faraday, is proved to depend on chemical action, and the negative pole from my own experiments is proved to be useless, except as affording the means for the removal of the second element of the compound fluid, then it follows as a natural consequence, that if the chemical affinity of any substance for one element of a compound fluid is greater than the resistance offered to the evolution of the second, force is produced. Now it immediately occurred to me that some metals might be made to reduce from a solution of one of their own salts, metal of the same description, by placing the metal partly in a solution for one element of which it has great affinity, and partly in a solution of one of its salts. This was actually found to take place in various cases, by following the facts that were made out respecting the ease with which hydrogen reduces various salts.

Zinc reduces zinc by taking a piece of the metal and doubling it, one half is then to be amalgamated and placed in

dilute muriatic acid, and the unamalgamated into a strong solution of chloride of zinc, made as neutral as possible, when the affinity of the chlorine for the muriatic acid is sufficiently great to cause zinc to be reduced at the other end of the same piece of metal. The use of platinum, palladium, silver, copper, or any other metal appears not to increase the action in the least, which experiment shows most powerfully the utter fallacy of the contact theory, or in other words that the voltaic force is in any degree dependent on the opposition of one substance to another. In this experiment according to the advocates of this now untenable doctrine, the force should have set from the amalgamated zinc to the mercury, the two metals, according to these visionaries, having from simply looking at each other the property of evolving power, but we find that the chemical affinity determined the course of the current.

Copper may by very simple means be made to reduce copper with truly great rapidity; for if a test tube be half filled with sulphate of copper, and then muriatic acid be poured gently at the top, so that the two fluids do not mix to any great extent, and a copper wire be then placed throughout the whole length of the tube, it will speedily show signs of action. The copper in the acid will rapidly dissolve, whilst copper will be as freely deposited at the lower part of the vessel. Now copper will undergo no action alone, either in muriatic acid or sulphate of copper. This experiment may be varied by the use of different acids or even some salts at the upper part of the vessel, for although muriatic acid shows this experiment most strongly, dilute sulphuric acid or muriate of ammonia will produce the same result.

Silver reduces silver by placing one end of a silver wire in a porous tube containing nitrate of silver, the other in dilute sulphuric acid, though the metal placed in either separately is not affected.

Lead reduces lead by immersing one end of a piece of

lead in a solution of the tris nitrate of lead, the other in dilute nitric acid.

Tin reduces tin by placing one portion of a piece of metal in muriate of tin, the other in muriatic acid.

Gold even reduces gold by immersing one end of a gold wire in the chloride, the other in dilute muriatic acid, the two solutions being separated as in all the former cases by a porous diaphragm.

There is a beautiful experiment detailed by Mr. Grove, which is analogous to those last described, though he attributed the results to a different cause. His experiment is to place two pieces of gold wire in muriatic or nitric acid, separated by a porous diaphragm, when no action will take place on either, but on being connected, that in muriatic acid will rapidly be dissolved, and the nitric acid will at the same time be decomposed by the hydrogen transferred to the other part of the wire.

From the various experiments which I have examined, added to the extensive researches of Faraday on the chemical portion of the voltaic pile, the voltaic force may be defined to be certain effects produced by the chemical action of a body on one element of a compound, and manifested between this point of action and the evolution of the second element. It might in other words also be defined to be peculiar properties evinced between the chemical action of a body on one element of a compound, and the evolution of the second element, the point of abstraction and subsequent combination of the first element being called the positive pole; the point of evolution or removal of the second element of the compound body, the negative pole. Hence it might be called circular chemical action, because the phenomenon always evinces itself as a circle.

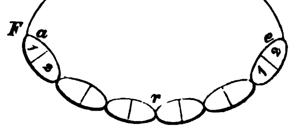
These definitions suit equally every possible case, and there is but one point included in those definitions which is uncertain, though as they now stand, whichever way that doubtful

case be taken, they equally apply. The difficulty, and the only one, that I know concerning the production of the voltaic force, is an uncertainty whether the force is produced by the analysis of the compound body, or the synthesis of the newly-formed salt. This is a point concerning which, perhaps, we shall ever be ignorant, yet analogy would rather lead us to suppose that the combination rather than the analysis is the source of the voltaic force. These definitions show why we cannot obtain the force from the union of two elements; indeed, we can never hope to obtain voltaic power from ordinary combustion, for though the energy of the combination of oxygen with carbon is immense, there is no second element, and therefore no intermediate point at which the effects can be manifested. For the same reason no force can be obtained from the union of liquid sulphur or bromine with metals.

The intensity of chemical action being always proportionate to the voltaic power, and being the only source of power in the pile it follows, that (I) the intensity or the power the voltaic fluid possesses of overcoming obstacles is equal to (F) the affinity which regulates the chemical action. But as we find that this power is lessened under different circumstances, $I = F - O$. O standing for the whole of the obstacles afforded to its passage.

Let us take at once a circle and examine its properties. We find that the intensity of the action (I) is equal to the affinity (F) of the body used to separate one element of the compound fluid (in the galvanic battery this is produced by the zinc and oxygen) lessened by the mechanical resistances afforded by the removal of the newly-formed compound (*a*) by the obstruction offered to the passage of the force by the compound solution (*r*), by the imperfection of the conducting

Fig. 28.



power of the solid parts of the circuit (c), and lastly, by the obstacle which is afforded to the removal of the second element of the compound fluid (e); thus we have algebraically $I = F - \overline{a + r + c + e}$. This circle is supposed to consist of but a single atom of fluid, exposed at one time to the action of the body combining with one of its elements, and all the resistances are supposed to be constant.

Sometimes this circle is exceedingly small, the (r) consisting of but one atom of the compound, and the (c) but of a single atom of the body combining with one element. This might be called properly an atomic circle, a good specimen of which has heretofore been called local action.

We must now consider the different parts of the circle in detail. F the chemical affinity of a body for one element of a compound is immensely strong where zinc is employed, the attraction of that metal for oxygen being most powerful; but if we substitute iron, tin, lead, copper, or gold, for the zinc, the attraction being feeble the value of (F) would be reduced in various proportions, in some cases almost to zero.

(a) the removal of the newly-formed compound affords but little resistance when the new salt is soluble in the fluid and a sufficiency is supplied for that purpose. In batteries generally the removal of sulphate of zinc affords but little obstacle, being quickly dissolved by water.

(r) varies very much from the extent of the interposed fluid, and its conducting power being very different in each case. It varies much in different batteries. Sometimes r is a very complex quantity, as when two or more fluids are used between the combination of one element of a compound and the evolution of the second. In Daniell's battery, for instance, it is made up of three parts, not only the resistance offered by dilute sulphuric acid and solution of sulphate of copper, but also a resistance offered by the interposed diaphragm. It might be made up of a far greater number of

parts, for different parts may be of different temperatures, which alone (if the temperature interferes with the conducting power) would cause r to be complex.

(a) the resistances of the connecting part of the arrangement is generally in batteries very slight, because we select metals which conduct pretty freely; (c) may be very complex, by being made of a variety of conducting substances, thus, if the connexions are made of wires of different kinds of metal, a different resistance is offered by each. (c) in every battery, is generally made up of three parts, the conducting power of the positive and negative plates, and the intervening connecting wires.

(e) the resistance to the removal of the second element, is generally very great, affording a considerable obstacle in all cases, but the differences in this respect are very remarkable. Ordinarily (e) is a simple quantity, but becomes complex when the hydrogen is removed in a variety of ways at the same moment. It becomes a curious question to ascertain whether (e) might ever be made a plus quantity. If the force proceeds from analysis, then the use of any body having great affinity for the second element might cause the current to be increased. If from synthesis, and this is most probable, if not absolutely certain, (e) can never be a plus quantity, but always a minus. In the removal of the second element by decomposition of another compound body, it is by no means uncommon for a voltaic circuit to be formed. In Grove's battery the hydrogen acts upon nitric acid, forming water, and setting deutoxide of nitrogen, &c., free; but in this case the intermediate part between the combination of the first element and the removal of the second, is only the atom of hydrogen, it therefore follows, that this action must be regarded as nothing but a series of little local batteries, or atomic circles, having nothing to do with the great battery which we make available for our purposes.

It is absolutely essential, according to our definition of the

2 C

voltaic force, that to be enabled to apply this principle for any purpose, however small a quantity of the force may be required, that either (*c*) or (*e*) should possess a capability of being so far prolonged as to enable us, with the imperfect powers that nature has furnished us, to handle or deal with these intervening portions of the circuit.

In the principal batteries now in use, their relative powers and attributes may be fully understood by considering each of the above properties in their construction.

	F	*a*	*c*	*r*	*e*.
Grove	large	small	small	medium	little.
Daniell	large	small	small	most	much.
Smee	large	small	small	small	much.
Smooth platinum	large	small	small	small	enormous.

Thus the four batteries may be considered equal in the properties of the F, *a*, *c*, the differences being only in (*r*) and (*e*). In Grove's the (*e*) is so small as not only to compensate a slight increase in the (*r*) over mine, as usually constructed, but to give a great advantage to his form of battery. In Daniell's the (*e*) is perhaps rather smaller than in mine, but that is more than counterbalanced by (*r*) being larger in Daniell than in mine. The effect of these properties are, that F in Grove's is diminished but little, F in mine more, in Daniell's more still; and in the smooth platinum battery by far the most. Thus is explained the decomposition of dilute sulphuric acid between platinum plates, by one cell of Grove's battery, and the same result not being obtained by the others. This equation is not only valuable for batteries, but applies to every single case where any substance acts upon a compound fluid in such a way as first to decompose it, then to combine with one of its elements, and set free in some way the other. Thus, if potassium be cast into dilute muriatic acid, (F) is immensely large, potassium having a violent affinity for oxygen; (*a*) is exceedingly small, potash being readily soluble in water; (*r*) is almost nothing, only one atom of fluid being traversed by the force; (*c*) is prac-

tically nothing from the same cause; (*e*) is very small. The result of such a state of things necessarily causes a vast intensity of action, and an explosion is the result.

Good specimens of contrasts in the magnitude in the several parts of the circuit are to be seen in the relative power of (F), as obtained by zinc and silver; in the relative resistance of (*a*) in the solubility of sulphate of lead and sulphate of zinc; in the resistance of (*r*) in the conducting power of pure water and muriatic acid; of the resistance of (*c*) in a leaden wire a hundred miles long, and a short silver one; in the resistance of (*e*) in the evolution of hydrogen from smooth platinum, and its removal by nitric acid.

The relative degrees of action evinced by zinc, tin, iron, and lead upon sulphate of copper are easily explained; (F) differs from being larger, (*a*) in being smaller when zinc is employed, whilst (*c*), (*r*), (*e*), in each case remain nearly the same; (*a*) indeed is so large when lead is employed as soon to put a stop to the action.

How intelligible is the want of action of dilute sulphuric acid on amalgamated zinc, if examined by our equation for (*e*); the adhesion of the second element, hydrogen, being increased enormously, counterbalances (F), the affinity of zinc for the first element, or oxygen, and no action takes place. Amalgamated zinc is rapidly dissolved if placed in a solution of salts of copper or silver, for (*e*) in that case is depressed, the hydrogen rapidly reducing the copper. Nitric acid in the same way does not respect the amalgamation of the zinc, for (*e*) in that case is also diminished by the removal of hydrogen from the decomposition of the acid. As the adhesion of hydrogen to plumbago is very great, it occurred to me that the simple application of black-lead to zinc would, by preventing the evolution of hydrogen, increase (*e*), and therefore stop the local action; but although the experiment fully succeeded, the plumbago so quickly came off, that I have not at present made any practical application of the experiment.

The above cases, with all their analogies, are not the only ones to which the equation applies, for it will account perfectly for the action of bodies on each other.

In cases of single elective affinity, as the action of sulphuric acid on nitrate of barytes, a compound is decomposed, one element enters into another combination, the other is set free; a voltaic circuit is therefore produced, the parts of which are thus made

$$\begin{array}{rll} & (c)\ \text{Sulphuric acid} & \rbrace\ (F)\\ (r) & \lbrace\ \text{Barytes} & \rbrace\ (a) \\ & \lbrace\ \text{Nitric acid} & \ (e)\end{array}$$

In cases of double electric affinity, as the action of sulphate of ammonia on nitrate of barytes, a similar circuit is formed thus:—

$$\begin{array}{c}(c)\\ \hline \begin{array}{r} (F)\\(a)\end{array}\left\{\begin{array}{ll}\text{Sulphuric acid} & \text{Ammonia}\\ \text{Barytes} & \text{Nitric acid}\end{array}\right\}(e)\\ \hline (r)\end{array}$$

In both these cases, however, we have not the means of increasing the (r) and (c) to a tangible size (at least I have never been able to do it), and at present these actions have been restricted to the formation of atomic circles.

There are some cases where we can extend the intermediate parts (c) and (r), and then our definition of the voltaic force with the formula arising from it enables us to form most extraordinary voltaic circles, which indeed we never could have formed before, unless we happened to light upon them by chance: thus proto-sulphate of iron, placed on one side of a diaphragm, and nitrate of silver on the other, will give a current when connected with a platinum wire, and a beautiful deposit of silver will be reduced on the platinum wire, on the nitrate of silver side of the circuit.

In the same manner circuits may be formed of proto-sulphate of iron and chloride of gold — of proto-nitrate of mercury and chloride of gold—of oxalic acid and chloride of gold, &c. In all of which cases the metal is freely reduced

on that part of the platinum wire inserted in the metallic salt. The reason why a galvanic circuit is formed in these cases is sufficiently obvious; water is the electrolyte or compound decomposed, proto-sulphate of iron is the substance combining with one element, and the metallic salt affords a means for the removal of the second element or hydrogen, and as we have the power of extending the compound (*r*) and connecting parts (*c*), not only an atomic circuit, but a working battery may be made. At the diaphragm or the point of juncture of the two liquids, indeed, an atomic or local battery is formed independently of the general or working battery. The following are the parts of the circuit in the above cases.

	(*c*)	
(F)	Proto-Sulphate of Iron	Platinum Wire
*(*a*)	Oxygen	Hydrogen (*e*)*
	(*r*)	

It would be extremely interesting to find every case of decomposition of a compound fluid obedient to the equation, and indeed there is every appearance of that being the fact.

The impossibility of giving a negative tendency to a metal when hydrogen is removed from its surface is also perfectly accounted for by our equation; for hydrogen, as has been already shown, protects the metal; so when a facility is offered for its removal not only is the direct protection removed, but by diminishing the value of (*e*), (F) the natural affinity of the metal for one element of the fluid, having but little resistance opposed to it, begins to act, and the metal is therefore dissolved.

The superior action of a rough metal in contrast with a smooth one is explainable on the equation most satisfactorily, for in the first case the affinity (F) is opposed by the resistance to the evolution of the hydrogen (*e*), whilst in the latter case (F) is so strongly opposed by (*e*) that no action can take

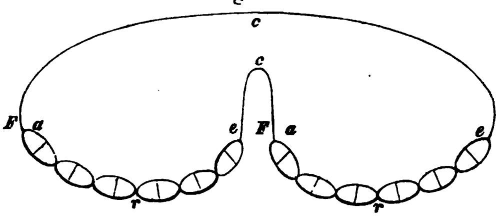
* (*a*) is the removal of the proto-sulphate of iron by solution; (*e*) is the removal of the hydrogen by the decomposition of the metallic salt.

place. Zinc shavings, which always have one side bright and the other rough, show this phenomenon clearly.

Hitherto we have considered (F, a, c, r, e) in every case to be constant, but in many instances they are subjected to continual variation. I do not, indeed, happen to recollect an instance of (F) varying to any amount, but (a) varies frequently; in the gradual saturation of a fluid it progressively increases, so much so, as at last to equal (F). This accounts for zinc ceasing to be dissolved on the saturation of the fluid by sulphate of zinc, although still intensely acid. (c) generally remains constant. (r) is very unsteady, for as in all voltaic arrangements the fluid is always undergoing change, it is therefore sure to be altered in its conducting power. (e) is subject to great variations from alteration of the liquid and other causes.

In every case of a single battery we have seen that the intensity is equal to chemical affinity, minus the resistances to that affinity. In a compound battery the expression is equally simple, for the intensity is equal to the sum of the affinities, minus the sum of the resistances. In a series of batteries all of the same nature, $I = \overline{F - \overline{a+c+r+e}} \times n$. Sometimes ($n$) is very complex. For example, if a compound battery be made up of a Groves', a Daniell's, and my own, the values of (I) must be considered separately, and their sum taken.

Fig. 29.



The diagram exhibits well the arrangement and properties of the compound battery.

A good example of the affinity of (n) is seen in the water

battery, where (I) is exceedingly small from the resistances of (a) and (r) being large, but becomes amplified to such a degree by (n) as to possess prodigious force; indeed as it possesses a capability of being amplified infinitely by an infinite series completely insulated, a battery might be constructed powerful enough for the force to pass from one electrode, placed in the Thames at London Bridge, and the other in some river in Australia, though the resistances of (r) and (c) in this case, from their extreme length, would be very great. In every water battery, as (a) instead of being constant gradually increases, the power gradually declines, at length to nothing. The curious and wonderfully-multiplying powers of (n), whereby the intensity can be increased, precludes our saying that the galvanic power is unable to effect any particular object; for, after all, it might turn out that (n) was not magnified sufficiently to attain that end.

When we are turning our power to some application it is very convenient to consider the purpose for which it is applied as a resistance, and call it R. If we have a series of them alike it would be $R \times n$. If, however, the series is not alike, it would be $R + R' + R''$. The intensity of the current here would be also equal to the sum of the intensities, minus the sum of the resistances. $I = \overline{I - R}\, n$. The R is frequently very complex, as in the reduction of metals in a decomposition trough, where it is made up of as many parts as a voltaic battery.

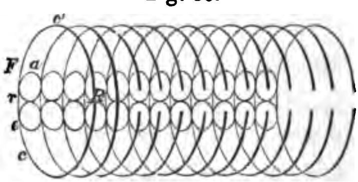
Having amply discussed the power of the force to overcome obstacles, we are led to determine the time in which any given number of equivalents of voltaic power can be obtained. Hitherto we have considered the circuit to be made up of a single atom of the body combining with one element of the compound, and if the affinity exceeds but ever such a trifle its obstacles, then in time any amount of work would be performed provided the current remained constant. A current can easily be conceived so feeble as to take millions

of years to reduce a pound of copper. If the entire circuit of single atoms be increased at every part, in fact if the mathematical voltaic circle be increased to the size of a tunnel, then (W), the amount of work performed in a given time, would be equal to the intensity of the battery, minus the resistance of our working apparatus, multiplied by the number of parts of the tunnel (A) thus: $W = \overline{I - R.} \times A.$

This equation, however, gives us the total amount of chemical actions in the whole series of batteries and decomposition troughs, or, in other words, the sum of the actions evinced in each; we generally, however, are desirous of estimating the amount done in one particular cell, in which case we divide our equation by the number of cells and troughs (n) thus, $W = \frac{\overline{I - R} \times A.}{n}$

Sometimes this equation is rendered extremely complex by an increase of the circuit at one side but not at another; in fact, the tunnel is cut away on one side, and this is a case that is perpetually occurring in practice. In this case it is not impossible but that the force is only derived from those parts of the circuit which are complete; in that case the equation would be $W = \frac{\overline{I - R} \times \overline{A - p.}}{n}$ p standing for the incomplete parts. In this view of the question we are supported by the analogy of water running through a pipe of given dimensions from a cistern, for however large this cistern be, provided there be no more pressure, the water running through the pipe would be the same. So far as the voltaic fluid is concerned I feel certain, from numerous observations, that beyond a certain point the increase of a battery does not cause a greater amount of electricity to pass through a given resistance;

Fig. 30.



and, perhaps, in those cases, where the enlargement of a battery increases the voltaic force, the battery in the former instance was deficient in size in relation to the size of the resisting part R, the tunnel, in fact, having been defective originally in that part. It is possible that the expression for this condition might be altered; for R, the resistance to the single voltaic circle, might possibly vary in some new manner, for which further experiments are wanted. In that case it would be $W = \frac{IA - \mathfrak{R}}{n}$. The old English $\mathfrak{R}$ standing for the new resistance afforded to the whole current. The tunnel might be cut away at any other part besides (R), thus it might be deficient at (F), (a), (c), (r), or (e); but the student will readily perceive the expressions for these cases.

Sometimes W is very small, as in De Luc's columns, where the total amount of chemical action, although (n) is frequently 500 to 1000, is so small that experimenters have even denied its existence; but when we consider that these very persons assert, that as soon as chemical action does become decidedly manifest, the action ceases, how strongly do they favour our views, for, according to our equation, we expect (a) to be gradually increased till all action would be stopped. W indeed, according to our equation, might be so small, as not to be cognizable to our senses for weeks, months, years, or centuries; and yet multiplied by a very large (n) would show enormous intensity or power of overcoming resistances.

The present modifications of the theory of galvanism are perfectly consonant with every practical direction given in the preceding pages, and the only difference in the theory will be found in the uncertainty expressed upon the contact and chemical action theories. Indeed, in page 54 the result is almost given in words though not in letters. By removing the slight difficulties which appeared to envelope the latter theory, by showing the necessity for a negative pole to cause power is unfounded, the beautiful doctrine of Faraday is

placed on the surest foundation, and the extraordinary and dogmatical paradox of a power without a cause is proved to be a fanciful chimera.

With regard to the connexion of the voltaic power with that of electricity produced from other sources, perhaps it might be expected I should say a few words. In the voltaic battery (I) is small, but may be increased to any size by (n), and as we have the power of increasing (A) also unlimitedly, we can perform any amount of work per second, indeed we might throw down hundreds of tons of copper per second, if we were disposed to make our circuit large enough. In frictional electricity (I) is enormous, but (A) is depressed to its utmost limit, so that not having a perfect command over (A) to increase it indefinitely, we cannot at present obtain what work we please in a given time. In animal electricity (I) is great, (A) is moderately large. In thermo-electricity (I) is depressed, perhaps increasingly, so that although (A) and (N) may be multiplied indefinitely, yet, practically, we should never be able thoroughly to overcome the smallness of (I). In that mighty operation of Nature which has just occurred, where the noise accompanying the discharge of the electricity over the metropolis was so awful as to alarm not only delicate females, but the stoutest hearts of men, and even the heretofore unterrified nervous system of infants—in that terrific storm, when every living creature trembled, and Nature seemed almost alarmed at her own operations, how vast was (I)! how large (A)! O! therefore that I could but have imprisoned that collection of force which in discharging itself committed such devastation on houses, churches, and trees, and, having encased it, been able to have let it loose as it might have been required; then indeed would all batteries be henceforth discarded as playthings for children—philosophical toys to be admired, still despised, for (I A) being unlimitedly great, we could obtain what work we pleased in any given time, at no expense.

The estimate of the parts of (I) in other cases where force is produced, *i. e.* an electricity not proved to be derived from chemical action, I do not deem it my business now to consider, but great difficulties would attend its accurate investigation, as it is almost impossible to magnify the size of the circle in these cases, in such a way as to make the action in each part cognizable by our senses. It is however quite evident that as in the voltaic and thermo circuits (I) may be magnified to any extent by (N), that the power of (I) in every case might be brought to the same standard in the power overcoming the resistances R′ R″ R‴ &c.

The obstacles to the completion of the voltaic circuit (O), are made up as we have seen of several parts, *a*, *e*, *r*, *c*, but, although they differ in kind, still as they have similar resisting properties, a perfect table might be made, referring them to one given standard, showing the separate value of each. The principle on which it should be constructed, is the law of the completion of the voltaic current, detailed when treating of the reduction of alloys; and as soon as we have this table accurately and numerically drawn up, the principles of the passage of the voltaic circuit, which formerly puzzled the most enlightened experimenters, will be rendered certain, and the difficulties will be also reduced to the facility and certainty of common arithmetic. Having obtained perfect tables of (O) and its several parts, we can readily obtain the relative value of (I), derived from various sources, by finding out what extent of (O) neutralizes each individual (I), and the value of (I), or the force of any battery, will be determined with equal facility. Complete tables of (O) and (I) now become the greatest *desiderata* not only to Electro-metallurgists, but to all who use the voltaic battery.

I now bid adieu to my theory of galvanism and my formulæ, and to those who have neither time nor inclination to dive into these mysteries, remember, in all operations that the sum of the resistances does not exceed the sum of the inten-

sities; and that in increasing the circuit, every part is equally enlarged. To those who have devoted themselves to these properties remember they will be useless if not brought into active operation; thus, if any difficulty occurs in your voltaic circuit, refer it at once to its proper head, and the operator may be sure that a continual practice and habit of using these formulæ will enable him to conduct his proceedings with a certainty never obtainable by blind experiment.

In concluding these formulæ, I herewith leave theory and rationale altogether, for having completed the principles, as far as I am capable, of everything relating to electro-metallurgy, I shall enter at once into the applications of the science for the direct purposes of the Arts, and although, everything that will be contained in the subsequent parts of this work has already been comprised in the parts already finished, yet there are many little practical difficulties to be surmounted — many little circumstances to be pointed out which the operator is likely to overlook or forget in conducting his operations, and these are the circumstances to which the concluding pages will more especially be devoted. Henceforth the work will be entirely practical, as heretofore it has been exclusively theoretical. There is a reproach attached to the very word, theory; the sense in which it is employed means rather rationale than theory, for whilst it has been my constant endeavour to shun theories without facts, I have tried and tried hard to generalize all extensive series of facts, and to give the rationale of every circumstance which is likely to occur to the operator.

BOOK THE THIRD.

ON ELECTRO-GILDING, PLATING, &c.

(192.) The infilming of one metal by another, is a subject of much interest, and the process has received different names according to the metal employed for that purpose. Thus, when gold is used, it is termed gilding; when copper, coppering: silver, silvering, or plating, &c. In every one of these cases we have to be careful that the two metals adhere, and for this purpose we take means to prevent any film of air, oxyde, or any non-conducting substance, from remaining on the first plate, as that would cause a separation between the metals. We apply heat, we scour the plate, or where it is possible, we slightly act upon the surface of the metal to receive the new deposit, taking care thoroughly to wash the metal after this operation.

(193.) * Electro-gilding is, in most cases, remarkably easy,

* Mr. Brayley, librarian to the London Institution, has been so kind as to call my attention to a process for electro-gilding practised by Bragnatelli, an Italian chemist, and noticed in the *Philos. Mag.* (First Series), 1805, vol. xxi., p. 187. It is singular that one of the supposed novelties of our own peculiar time should be discovered to be upwards of forty years old, a circumstance which we must more fully notice when treating of the history of electro-metallurgy.

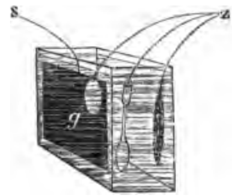
for if care be taken to follow the laws which have been already detailed, it will be attended with very little trouble. The metal to receive the gold, may be either platinum, palladium, silver, copper, carbon, gold itself, or indeed almost any other metal, when the auro-cyanide of gold is employed. The surface should be chemically clean, and freed from adherent air, either by plunging it into nitric acid or a solution of potash, or by heating it and then quenching it in acid. The smoother the surface, the more favourably the deposit will take place upon it, for a very rough surface is not quite so well adapted for these operations, the hydrogen having a greater tendency to be evolved from it. When the metal to be gilt does not decompose the solution of gold, the solution may be stronger. When, on the contrary, the metal acts upon the solution, it must be weaker. The electrical current must be suited to these varying circumstances, and in general but a feeble current is required.

Pursuant to the plan I have already laid down, the best process in each respective department of electro-metallurgy will alone be detailed; and those who desire to use other solutions or other processes, are referred to the second book of this work; in the four chapters of which he will find such information as will enable him to make the alterations he desires with profit and success.

(194.) For all cases of electro-gilding the auro-cyanide of potassium makes by far the best solution. It is scarcely decomposed by any metal. It may be prepared by digesting oxyde of gold in a strong solution of cyanide of potassium, but its mode of preparation has been amply detailed when treating of the reduction of gold. For our present purpose, a strong solution of the salt is to be preferred, and, from the corrosive nature of the cyanide of potassium, it should always be placed in a glass vessel. For gilding, it would be folly, nay, almost madness, to use any other process than the battery, of which the single-battery process will answer every purpose

where time is not an object, and is indeed as a general rule to be much preferred; but if great speed is required, the compound battery made of two, three, or four batteries must be employed, or more cyanide of potassium must be added to the solution of gold. The size of the battery need never exceed the size of the object to be gilded, though if it be larger, it will not be of any material consequence, as a strong obstacle to the passage of the current is situated at the positive gold pole. The positive pole, as a general rule, should consist of a piece of pure gold flattened, and the part exposed to the solution should not exceed the size of the object to receive the deposit.

Fig. 30.



Every portion of the object on which we are desirous to have no layer of gold, must be coated with tallow, wax, or any other non-conducting substance, the presence of which will prevent any deposit from taking place on those parts. In this way, an object may be coated to any desired limit, or upon any circumscribed parts of its surface, as, for example, drawing or writing thereon. The rapidity of the process may be regulated to the greatest nicety by placing more or less of the positive plate of gold in the solution, by which means, as in other cases, the quantity of electricity passing may be regulated with the utmost precision.

The time occupied for the process must vary according to the amount of electricity passing, and the quantity of gold required to be deposited; but the thickness of the deposit can at any time be learnt, either by ascertaining the additional weight it has received, or by the reduction which the positive gold pole has suffered.

To conduct this elegant process with the greatest economy of time, the quantity of electricity should be so regulated to the strength of the metallic solution, that the hydrogen is kept below its point of evolution from the negative plate; for

we must always bear in mind, that the evolution of hydrogen is attended with evil, as the precipitate will then be in one of the finely-divided states, or even as a black powder.

During the process, particularly if the object have a rough surface, it is a good plan to remove it from the solution before the completion of the process, and rub it with a hard brush and a small quantity of whiting or rotten-stone and well wash it; by these means, any finely-divided metal will be removed, and the gold will be precipitated in a very even manner. This cleansing is not required when the deposition takes place very slowly from the auro-cyanide of potassium. The colour of the gold, if the precipitated layer be very thin, will be a greenish yellow, but when thicker it will be the natural colour of the pure metal.

The state of the surface of the reduced gold varies with the rapidity of the process, in relation to the strength of the metallic solution. If reduced very slowly it will assume the beautiful frosted appearance of dead gold. If deposited more rapidly the surface will have a brighter appearance. If still more rapidly the surface will again begin to be brown, and quicker than this the operator must not conduct his process; for then the spongy deposit begins, which the electro-gilder should shun as the very bane of his art.

All objects of silver may be readily gilt in this way, and objects of copper with as great facility as those of silver. Some suppose, and, perhaps, with good truth, that copper articles require less gold than silver ones; the silver when heated having the property of taking into itself a certain portion of gold. However, copper is more difficult to bring into a thoroughly clean state than silver, especially in deep crevices. For those cases it is better to plunge the copper article into some acid solution of a metal which it can spontaneously reduce; for instance, into dilute sulphuric acid, containing a trace of either nitrate of silver, chloride of platinum, palladium, or gold, the object of which immersion is

not in any way to leave a deposit of the new metal upon it, but thoroughly to cleanse the surface. After this immersion the object may be washed, and as much of the reduced metal as possible rubbed off by means of a hard brush, when it will be found to possess a surface admirably adapted for the reception of the gold.

If we have a number of small articles to gild, we may suspend them in the solution of gold opposite to the positive pole; and especial care must be taken that each part of the object is exposed for the same length of time opposite to, and at the same distance from, the positive pole; for any variation in this respect would cause a different thickness of gold to be deposited. The workman may be well assured, that if any article has an unequal coating of gold, it is owing either to some of the above causes, or that a different relative amount of the positive plate of gold radiated to the various parts of the object. An imperfect layer of gold betokens imperfection in the cleansing of the object before immersion. Electro-gilding is applicable from the finest platinum wire to any object however large, and no doubt the dome of St. Paul's could be gilt as readily as a silver thimble if any person could place it in a proper apparatus.

Whatever be the object to be gilt, it is highly important that every part should be entirely immersed in the liquid, or else, that part at the junction of the air and water might be liable to be rapidly dissolved.

The extent to which gold is applied to silver and copper articles is very great, and no variation is required in the process, except in those cases where the object itself may form a decomposition-trough—as silver vases, the bowls of large ladles or spoons, where it is only necessary to fill them with the solution of the auro-cyanide, which in this case, should contain no free cyanide of potassium; connecting them by means of a wire with the zinc of a battery, and inserting a plate of gold in connexion with the silver of the battery in the interior of the

solution, taking care not to allow the gold and vessel to form a metallic contact; but even in these cases it is far better to immerse them entirely in the liquid for reasons before stated. All these cases of gilding appear to be rather for appearance and beauty than utility; but sometimes metals are coated for the protection which the coat of gold affords: thus the hair-springs of chronometers have lately been gilt by this process, and patents have been taken out for its application—a circumstance to be more fully considered when treating of the history of electro-metallurgy. The gilding of iron and steel only differs from gilding silver and copper in the necessity to be careful to overcome the difficulty which occurs in most thoroughly cleansing the iron. It should be plunged into dilute sulphuric acid, and allowed to remain for a short time in that fluid before being immersed in the auro-cyanide; and if we wish most thoroughly to protect the metal from the action of extraneous causes, a tolerably thick layer of gold should be used. I am informed that the application of heat to the auro-cyanide favours the adhesion of the metals.

Some years ago the attention of engravers and etchers was directed to the application of gilt copper-plates for their art, instead of plates prepared with the biting ground, as now employed; but a difficulty arose in coating the surface so thoroughly as to resist nitric acid in every place, except where, by the aid of his etching instrument, he cut through the gilt. It is not improbable but that electro-gilding might be now employed for this object, and, indeed, I recollect seeing the fact mentioned in one of the Journals, but I am unaware whether it is at present practically carried into effect.

Clichees and objects of lead, tin and pewter are rather difficult to gild in the same way, because their surfaces, although scraped very clean, seem to become coated with an insoluble cyanide which prevents a good cohesion. It might perhaps be a good plan to coat the surface with the slightest layer of copper by immersing it in verdigris dissolved in vinegar.

The electro-gilder will occasionally find that his salt will get into a very inactive state, apparently without any cause. The subject is deserving further inquiry, but I would venture to assert, from facts that have come to my knowledge, that it is owing to the absorption of oxygen, either from the atmophere or at the positive pole of the trough. This circumstance, therefore, should at any rate be avoided, by leaving the solution when not in use as short a time as possible in contact with the air, and by increasing the size of the positive gold pole when we desire a large current of electricity to pass, rather than increase the series of batteries. The same observations apply to all the metallo-cyanides, for even the yellow ferrocyanate of potash will become changed into the ferrosesquicyanuret by long exposure of its solution to the air.

After any object is gilt, it is usual to colour it, by which much is added to its richness. If we wish simply to give the gold a darker colour, the following process is said to be well adapted: two ounces of alum, two of saltpetre, and half an ounce of sal enixum are well powdered together, and placed in a pipkin with about four or six ounces of water, and warmed over a fire; into this, one ounce of what is termed gilders-wax is placed, which is to be dissolved and gently simmered. The mixture must be allowed nearly to cool, when the object is to be plunged into it two or three times, and then withdrawn; the oftener the process is repeated the deeper the colour of the gold. It is then to be well rinsed in cold water and brushed with a nail brush. A green colour is said to be given by soft soap and alum. By the electric current alone, the colour of the gold may be varied considerably by variations in the quantity of electricity in relation to the strength of the metallic solution. In fact I have observed gold of every colour reduced from the auro-cyanide, and even other solutions.

In many cases the object as soon as removed from the precipitating trough, has only to be well washed in soap

and water, when it is quite fit for use; and in this state presents the appearance called dead gold. Sometimes the operator is desirous of having his object bright, either entirely or partially, so that the bright and dead parts may form a contrast with each other. In this case the object is dipped into a solution of soft soap, to which a little prussic acid is added, thoroughly to cleanse it, when an instrument called a burnisher (b), which is nothing but a bright piece of steel, the shape of which is suitable to the object to be burnished, is rubbed over it two or three times, and finally the process is completed by a blood-stone (s) fixed upon a handle. The operation of burnishing, is generally performed by women; and it is indeed remarkable that they should have learnt the use of prussic acid for cleansing gold, which has been employed for many years, especially when we consider that the fact was not known to chemists at the time. It is worthy of remark, that the solution of soft soap and prussic acid is admirably adapted for cleansing trinkets and all articles of gold when they have become dirty.

Fig. 31.

(197.) The process of gilding by galvanic precipitation from a solution of gold, is very different in its effects from the method formerly patented by Elkington, termed water-gilding; by the latter process the metal which is to be gilt is dissolved in an equivalent proportion to the gold deposited, and therefore as soon as a mere surface of gold is obtained, it has been supposed that no farther deposition can take place; but when the gilding is effected by the galvanic battery, any amount of gold may be applied upon the object; a consideration of no small importance, as upon the thickness of the coat must depend the durability of the gilding.*

* Mr. Cooper, however, in an admirable lecture delivered at the Royal Institution, stated that this opinion is unfounded, and that any layer of gold might be deposited by this process. His assertion shows that this mode of

It is not the solution of nitro-muriate of gold which is used for water-gilding, but a solution of the oxyde of that metal in potash. The solution may be prepared by adding caustic, potash, or its carbonate, to the ordinary solution of gold, in such proportion that the precipitate first formed is re-dissolved, when it is fit for use. To gild any article, it is plunged, after being first thoroughly cleansed, into the hot solution, and allowed to remain in the solution till a thin coating is obtained, at the expense of a small quantity of silver.

(198.) There are, besides these processes, other modes of gilding used in the arts; as gilding by amalgamation. In this case, a mixture of finely-divided gold and mercury is rubbed over the object, and the mercury is afterwards driven off by heat. This process is very detrimental to the health of the workman, as the fumes of mercury are extremely poisonous. It is to be hoped, therefore, that the process of gilding by the galvanic current, will, after a period, entirely supersede this most injurious operation.

In gilding very large vessels, the workmen are obliged to be extremely cautious not to submit themselves long to the action of the fumes; extraordinary contrivances have been used to prevent the inhalations of the metal. The old authors draw most dismal pictures of the horrors of mercurial inhalations, and not without cause, for it is not at all uncommon for the medical man to witness salivation, universal trembling of all the limbs, nervousness, nay, even death itself, from this powerful agent. It is a sad matter of notoriety, that as soon as the workman becomes the prey of the disease caused by following his business, the master dismisses him as an unprofitable servant, and casts him off as worthless dross.

A comparison between the durability of gilding by the galvanic process, with that by the other methods, can only

gilding must be more or less imperfect, otherwise the copper or silver would be prevented, by the coating of gold, from further action.

be made after the lapse of a considerable period; I find, however, that some spoons and other articles which I gilt by the battery, wear extremely well. The thickness of the deposit can be regulated with the utmost accuracy, from the thinnest possible layer to a coating of an inch in thickness.

Electro-gilding appears not to be generally applicable for non-conducting substances, for I have not at present succeeded in applying the gold to any extensive surface, although I have seen it grow, for a short distance, over blackleaded sealing-wax. Perhaps by using the strongest solution of gold, it may be possible to gild surfaces in that way.

Electro-gilding is generally an advantageous process; for the value of the materials used is trifling. It can be however repeated at pleasure; and probably an article could be nearly twice as thickly gilt by electro-metallurgy, at the same cost, as once by amalgamation, on account of the waste of gold and mercury, which always ensues in the latter operation.

(199.) Platinating metals by the galvanic current, is a new feature in science. The process is similar in all respects to gilding, but is more difficult. The best solution to be employed is the nitro-muriate of platinum, to which sufficient soda is added to render it neutral. The object to be coated should be smooth, and thoroughly cleansed by potash before the process is commenced. Having proceeded thus far, and the solution of platinum being ready, a fine platinum wire, in connection with the silver of a compound battery, must be placed so as to dip into the solution, but must not be immersed beyond a very short distance. The object to be platinated is now ready for connection with the zinc of the battery; after this is effected, it is to be dipped in the solution. (Fig. 23.) Immediately, oxygen gas will be given off from the platinum wire, in connection with the silver. From the copper or other metal to be platinated, no gas will be evolved, provided too much electricity be not generated. In a few minutes the object will be coated with platinum.

This process must not be confounded with that by which negative metals are prepared for my battery; for in this case, the platinum is precipitated of the colour and appearance of platinum, but in the latter case it is thrown down as a black powder. The first process I propose to name platinating, in contra-distinction to platinizing. To platinize metals, we use a strong current to throw down the metal in the black powder; to platinate, we may employ solutions of any strength, but we must use more moderate currents, so that the electricity is insufficient for the production of hydrogen.

An attempt has lately been made to form my battery of platinized lead * as a substitute for platinized silver, but with only partial success. Before publishing an account of the battery I tried lead, and even all its alloys, as solder, pewter, type-metal, fusible metal, &c., together with most other metals and alloys usually met with in commerce, but was very ill satisfied with the result; for many parts of the surface soon become imperfect from a deposition of sulphate of lead, independently of the imperfectly-conducting nature of the lead itself. I tried to obtain lead plated with silver, but did not succeed, being informed that the two metals would not roll together. Now, however, that we can silver lead by voltaic electricity, it perhaps might be employed; or we may palladiate the metal by simply immersing it in a dilute solution of the nitrate of palladium, and then platinize it. Upon the whole perhaps platinized lead is better discarded, unless silvered or palladiated, especially as we can always make a cheap battery of platinized iron if we want a battery of large surface to last a short period, and platinized plumbago, charcoal, or even cinders is preferable to platinized lead. To sum up in a few words my experience in the construction of the

* Perhaps platinized lead scarce possesses more than half the effective surface that platinized silver does; but it is a fact very difficult to ascertain, being the (IA) of my equation, which is by no means equal to the work performed when the battery is connected with a voltameter, because $W = \frac{\overline{I - R}\ A}{n}$.

battery; it is preferable that the finely-divided metal should be either platinum, palladium, or iridium, the first being best; and the metal to receive the deposit platinum, palladium, gold, silver, carbon, or iron; zinc, cadmium, copper, are the worst of all the metals; then follow tin, lead, and their several alloys, together with those of antimony and bismuth.

A cheap metal or alloy for the reception of the finely-divided metals that would not undergo the slightest change in dilute sulphuric acid would be hailed by electro-metallurgists as a great boon; perhaps some compounds of silver, zinc, and nickel might be discovered applicable for this purpose.

Specimens of electro-platinating which I have prepared by this method, will not resist the action of nitric acid, because there are generally some little fissures uncovered, some little crack which admitting the nitric acid tears off the platinum in thin scales. It is not applicable to rough surfaces, as it is preferable that the surface for its reception should be smooth. The colour of the metal thus reduced is so similar to polished steel, that it would be difficult to distinguish the one from the other. It is needless to say that it has a beautiful appearance. It would be of great value as a coating for telescopes, microscopes, quadrants, and a hundred other articles which must be exposed to the action of the weather.

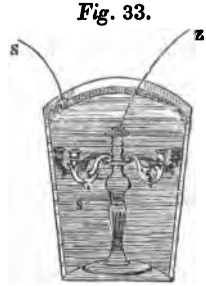
(200.) To palladiate articles, we adopt methods similar in all respects to those used in platinating them. We employ the ammonio-muriate of palladium dissolved in liquid ammonia, and employ the compound-battery process with a small positive platinum pole. The palladio-cyanide of potassium with a palladium pole may also be employed. This metal is whiter than platinum, but not so bright as silver. It might be used in the same cases, and with the same advantages as platinum; and we have, besides, twice the bulk of metal in the same weight.

Palladium adheres with such firmness to copper, when reduced by voltaic electricity, that it is almost impossible to

remove it when once deposited. It might be worth while for experimenters to ascertain how far it might be employed for the protection of iron or steel.

(201.) There is no process at the present time more readily conducted than electro-plating. The best solution which can be used is without doubt the argento-cyanide of potassium. It is generally made by boiling the oxyde of silver in a strong solution of cyanuret of potassium. The process which is most favourable is the single battery. The solution should be placed in a glass vessel, and used with a silver positive pole, about the same size as the object to be silvered. The same precautions should be taken and the same measures observed with regard to plating as gilding. The object should be clean, in order that a most perfect adhesion may be effected between the object to be silvered and the reduced metal. The silver will be thrown down in somewhat different states, according to circumstances. If thrown down very slowly it will assume a beautiful dead appearance; if still more rapidly it will be brighter. It is, perhaps, as well to use the solution as strong as possible, and take care to stir the liquid occasionally, in order that a proper diffusion of the metallic salt may take place. As a precipitating trough either the vertical or horizontal may be employed according to circumstances; the latter is to be preferred for large surfaces, as waiters, and similar objects: in which case a corresponding large plate of silver should be used as the positive pole and placed over the object to be silvered. Sometimes a large circular silver positive pole may be made to surround the object as in the adjoining wood-cut. The silver pole is to be connected with the silver plate of a battery, exposing nearly as much surface as the object to be plated, whilst the object to be plated is to be connected with the zinc. A little free cyanuret of potassium, added to the

Fig. 33.



argento-cyanide of potassium, hastens the process by increasing the solubility of the positive pole. The quantity of metal reduced can be readily ascertained, either by finding the additional weight of the object receiving the deposited silver, or by ascertaining the deficiency of the positive pole.

Plated articles may be either partially or entirely burnished in the same way as gilt objects, according to the fancy of the operator; and the contrast of dead silver with the bright polished metal much increases the beauty of the object.

Copper and its alloy are most readily silvered by this process; but lead does not take the metal so freely: it does indeed become coated; but the two metals have not generally a firm adhesion, because the lead, although made perfectly clean, becomes in part coated with an insoluble cyanide immediately it is immersed in the solution. Perhaps the best mode of remedying that would be to reduce a thin film of copper upon the object by immersing it in verdigris dissolved in vinegar, or by touching it with a solution of the nitrate of palladium, by which a slight film of metal would be reduced.

Now conducting substances can be silvered by first black-leading them, then attaching a wire in such a way as to come in contact with the plumbago. In this case we should be careful to use rather a larger plate of silver than the object, as that favours the growth of the metal, but as a general rule it would be preferable to coat the object first with copper and then silver it.

(202.) The mode in which articles are plated independently of electro-metallurgy, is very different from the one now used. It is customary to take an alloy of silver and copper about the standard used for coining, and to solder it on a bar of copper. This bar is then rolled out thin; by which means, as the two metals extend equally, the silver forms an exceedingly thin covering. This plated metal is then, by hammering, formed into the required shape, and soldered to other parts. The handles and edges are made of

thin silver rolled to about a square foot to the ounce, which is first embossed with a die, and then the hollow parts are filled up with solder. These steel dies at some manufactories have cost alone many thousand pounds. Now, although the silver on plated articles is so exceedingly thin, it is astonishing, if the goods are well made, as Sheffield goods usually are, how long the thin coat lasts. This excellent result is owing to the compression and hardening that the metal undergoes during the process of rolling. In this respect it is superior to electro-plating, but the process can never be repeated whilst electro-plating may be performed any number of times.

Electro-plating is of considerable advantage to the operator, for articles may be made entirely of copper, and even finished with laborious minuteness, and then silvered. The probability is, however, that electro-plated articles will not wear quite so well, in proportion to the thickness of the metal, as ordinary plating, for all metals reduced by electricity are formed not to resist attrition so well as rolled metals. Electro-plating is a cheap process, independently of the intrinsic value of the silver used.

(203.) Metals may be covered with nickel, by proceeding as in the former cases. The solution to be used is the chloride of nickel, with a nickel positive pole. The single-battery process is to be preferred, but pure nickel though very brilliant, is apt to be rather brittle.

(204.) Various substances, both metallic and non-metallic, may be coated with copper by the agency of the galvanic current. The various solutions to be employed, and the apparatus to be used, have been already fully described, when treating respectively of electro-metallurgic apparatus, and the reduction of copper. As a general rule, the single-battery apparatus is to be preferred, and an acidulated solution of sulphate of copper, as the salt from whence the reduction of copper should be effected. The solution given at page 157 is

well adapted for a smooth deposition of metal, but it must contain more metallic salt when we desire the crystalline deposits. The advantage of its application relates principally to non-metallic substances, which may, in this way, receive a metallic surface of pure copper. Not the slightest difficulty would attend the coppering of almost any metal; but as this is never likely to be required, there is no need to enter upon the subject.

(205.) Coppering non-conducting substances may be divided into two departments; the first of which contains those which require the deposit to assume, as nearly as possible, the form of the original substance; the second comprises those cases where the deposit is desired to be in a crystalline state.

A somewhat different arrangement is required in each instance; for in the first, the battery and solution must be so arranged that the hydrogen is near the point of evolution; but in the second, the solution may be much stronger, and the quantity of electricity may be increased by increasing the size of the battery, and the surface of the positive copper pole in the decomposition apparatus.

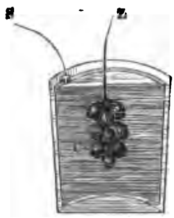
(206.) In the first division we have delicate substances, such as medallions, &c. The substances of which the cast is made should be rendered most thoroughly non-absorbent by the processes already described. For this purpose the medal must be boiled for such a time in wax, stearine, spermaceti, or tallow, till it becomes translucent, or semi-transparent. It is then to be brushed over with black-lead, and at the edge a very fine copper wire is to be once twisted, in order that perfect contact may exist between the battery and black-lead. It is now ready to be placed in the solution of acidulated sulphate of copper, the end of the wire having been first connected with the zinc of the battery. After this has been done, the last thing is to place a piece of waste copper in the solution, rather larger than the cast, and to connect it, by means of a wire, with the silver of the battery. Action

will immediately take place, the copper will be dissolved, and the metal precipitated on the black-lead of the object, spreading over the surface till the whole is covered. It is as well, perhaps, to use a large positive pole of copper and a small battery, so that the decomposition may take place very slowly, which causes the surface to assume a delicate matted appearance. In some cases we may use two batteries arranged as a series for this purpose, as that will ensure more rapidly the uniform spreading of the copper over the medal. The medal must not be left in long after it has been coated, as that will detract much from its sharpness and beauty; after it has been taken out, it may be rubbed over with coarse paper to remove any little asperity that the copper may have thrown up. To the numismatist this process will appear barbaric, as he would consider that it would detract from the beauty of the medal; but though decidedly detrimental, it is not so injurious as might at first sight appear to coarse objects; because as the copper is of nearly uniform thickness all over, the effect is to increase in size the whole design. To the sculptor and architect, perhaps, it might be used with advantage to coat statues or other ornaments. In all these cases it is advisable to coat not only the front but the back of the object with the metal.

(207.) A pretty application of the art of coppering is suitable to horticulturists, as by its means, fruit, vegetables, leaves, seeds, and various other specimens may be coated with copper, either for ornament, or for the purpose of illustrating the size, form, and other peculiarities of the object. Apples and pears may be very readily coppered; they are to be brushed over with black-lead, and then a small pin is to be thrust in at the stalk; to this a wire should be attached, which is connected with the zinc of the battery. It may then be placed in the solution, and the whole arrangement completed by the insertion of a piece of copper, which is to be connected with the silver of the battery. In a similar manner, cucum-

bers, gourds, potatoes, carrots, and a hundred other vegetables, seeds, and roots can be covered. The wood-cut exhibits a bunch of Portugal grapes submitted to the action of the fluid to be electro-coppered. The form, after the process, is characteristic, and marks so strongly the individual character of each variety, that the horticulturist is at no loss to distinguish the specimens at once. The condition in which the copper is thrown down, can of course be varied according to the laws set forth in the last chapter. For ornamental purposes, the crystalline copper is the most beautiful; but for a specimen intended to illustrate the form of the object, the smooth copper is best adapted. After the objects are completely covered, the pin is to be withdrawn, which will leave a little hole, and that enables the evaporating juices of the vegetable to pass freely out, and thus promotes the complete drying of the encased object. A cucumber which I coated during the past summer, appears now to contain scarcely anything inside the copper, and the pears, apples, &c., consist of little else but the metallic coat. The botanist will readily perceive in what way this process may be employed for his advantage.

Fig. 34.



The beauty of electro-coppered leaves, branches, and similar objects, is surprising. I have a case of these specimens placed on a black ground which no one would take to be productions of art. In the same room with them are a couple of those cases, in which Ward has taught us to grow in this smoky metropolis some of the most interesting botanical specimens. In these cases are contained varieties of fairy-formed adiantums, verdant lycopodiums, brilliant orchideæ, rigid cacti, and creeping lygodiums, all growing in their natural luxuriance. The electro-coppered leaves, however, are beautiful when placed by the side of the productions of this miniature paradise; and when I state that the numerous hairs

covering the leaves of a melostoma, and even the delicate hairs of the salvia are all perfectly covered, the botanist must at once admit that these specimens have rather the minuteness of nature than the imperfections of art.

(208.) A beautiful effect of metallic surfaces may be obtained by the deposition of crystallized metal on baskets. The wicker-work must be black-leaded, and connected by means of a wire to the zinc of a galvanic battery; when on being immersed in the metallic solution, and the circuit completed, it will be covered with the most beautiful crystals of copper, sparkling in the light from the facets of thousands of little crystals. It is as well to pass a very fine copper wire round several parts of the basket, so that it may touch the black-lead in several places, for this will insure the coating being more rapidly complete. Any other mode of giving a conducting surface will answer equally as well as black-lead. The copper pole for these objects should be very large, and a series of two or three batteries employed. The solution of sulphate of copper should be perfectly concentrated, for all these circumstances will tend to render the copper crystalline. Baskets thus prepared, and filled with metallic fruit, leaves, insects, &c., might be used as ornaments for the drawing-room, and would greatly exceed in interest the usual appendages; for if these objects were made by the individual who possessed them, it would show his interest in the noble science of galvanism; and if they were purchased, it would be the means of encouraging the application of this powerful agent to the arts and manufactures. It is now indeed, but a small germ, but will doubtless become a vast tree, which by bearing fruit will cause a mighty revolution in many manufactures. Let the attention of the wealthy be directed to the subject; let them patronize ornaments made by these means, and then speedily will the artizan become more perfect in his work, and the galvanic fluid will be as commonly used as steam or gas. I particularly dwell upon these circumstances in this

place, because most coppered objects are exceedingly beautiful, and many of them could not possibly have been made by any other process heretofore known.

In fact there is nothing organic or inorganic which will remain in a solution of a salt of copper a few hours, that may not be coated with the metals.

The foregoing electro-coppered objects are trifling compared to the purposes to which electro-coppering has been tried; for actually, experiments have been made to cover the bottoms of ships with that metal. There are two or three experimenters who lay claim to the first idea of the invention; one of them is Mr. Hays, a distinguished practical chemist of Portsmouth, and experiments have been tried at the dock-yard at Portsmouth upon the subject; Mr. Hays, first coats the bottom of the vessel with pitch, thoroughly blackleads it, and then attaches wires as a medium of communication with the plumbago, and the zinc of a very large battery. The vessel is laden with ballast till it sinks as low in the solution of acidulated sulphate of copper as it is desirable that the copper should extend. The solution of the metallic salt is placed in a suitable reservoir, and a large positive pole, composed of sheets of copper, is attached to the silver of the battery, which completes the arrangements. In this mode of proceeding the negative pole being above the positive, a proper diffusion of the newly-formed metallic salt cannot take place as readily as could be desired, and it would be attended with much trouble to turn the boat over, so that the positive pole might be arranged over the bottom of the boat; especially, if it were a first-rate man of war. In all large commercial operations, the expense becomes the most important consideration, and I am afraid that in this case, the cost of the reduction of copper when added to the labour required for the process will not at all compensate for the additional time that the reduced copper would last over the copper sheathing as usually employed.

(209.) Earthenware, or any other similar substance can be coated in like manner with the metallic copper; but when these smooth surfaces are to be covered, some difficulty arises, which may be overcome by the previous application of a very little varnish. In this way, by coating a jar with copper, a Daniell's battery may be made.

Electro-coppered objects may be gilt, silvered, or coated with other metals. Crystalline objects, however, are more beautiful in their cupreous character; though smooth objects, as leaves and fruit, are very beautiful when gilt. Electro-coppered objects silvered are not so striking as either of the other two, and this on account of the dull whiteness of the silver.

(210.) Metals may be coated with nearly every other metal, besides those I have so fully described. Some of these metals are found to be much more troublesome than others, and some will only give an irregular coating; yet, by following the principles explained in a former book, any metal may be thrown down in the reguline state, with more or less success.

(211.) Electro-tining is a process which, whether considered in its difficulty, inefficiency, inutility or expence, is equally disadvantageous. To obtain a thick layer of tin directly by electricity, would be extremely difficult; and although a thick layer may be readily obtained by depositing either crystalline or spongy tin, and then fusing it, I cannot see that any advantage is likely to accrue from such a proceeding. Perhaps the sulphate of tin is the best solution that can be used for this purpose, conjoined with the single-battery process.

Electro-leading is a process equally unfavourable in its results, as electro-tining. The tris-nitrate of lead makes perhaps as good a solution as can be employed for this purpose.

Electro-zincing is not attended with any great difficulty; the metal may be readily reduced from the sulphate, made as neutral as possible. The single-battery apparatus should be

employed with a zinc positive pole; any metal may be used to receive the deposit, taking care to employ it very clean, and the smoother it is the more favourable will be the result.

Metals may be readily coated with a beautiful deposit of iron, by using the proto-sulphate, or neutral chloride of iron. The single-battery process with an iron positive pole is best adapted for this object.

The facts in this book are generally new, and their application is extremely interesting; for to those who follow galvanic science as an amusement, the exercise of the arts of gilding, plating and coppering, will not only be interesting but useful; in the arts doubtless they will assume a higher importance, and add new branches for the successful application of electricity. Those who are desirous of following these processes as a business, will find that practice alone will make them perfect; and as the scientific man details the principles to be pursued, so the mechanic must follow these laws, and regulate the details as his extended experience may dictate.

BOOK THE FOURTH.

ON VARIOUS APPLICATIONS OF THE REDUCTION OF METALS BY GALVANISM.

CHAPTER I.

ON THE MULTIPLICATION OF COINS AND MEDALS.

Value of electro-metallurgy for the numismatist, 212. Mode of obtaining the mould, 213. Directly by the voltaic current, 214. By lead, fusible metal, &c. 215. By non-conducting substances, 216. Metallic duplicates of gold, 217. Silver medals, 218. Medals of platinum, 219. Copper medals, 220. Precautions to be taken to prevent air-bubbles, 221. Apparatus to be employed, 222. Single-cell apparatus, 223. Thickness of the metal, 224. Removal of the cast from the mould, 225. Zinc Medals, Iron Medals, 226. Value of electro-metallurgy for medalists, 227. On the modes of making perfect medals, 228.

(212.) To the numismatist, the reduction of the metals by galvanism is of the highest importance; for on the one hand it presents him with the means of having casts of coins or medals, which on account of their great rarity he could never otherwise possess, and on the other hand it offers to the coin-manufacturer the means of forging the more scarce coins, so that the collector must be doubly careful in making his purchases. At present, I am afraid that our art in unskilful hands, has been the means of destroying so many medals, that no benefit which has yet accrued has been able to compensate for their loss.

(213.) There are three methods of taking the duplicate of

a coin or medal. By the first, a primary cast or an intaglio is made in metal, directly by the galvanic precipitation; by the second, a metallic cast of the medal is first obtained, either in fusible, type, or analogous metals; and by the third, we make the intaglio cast in some non-conducting substance, as white wax, sealing-wax, &c.

(214.) To take a primary cast at once from the medal or coin should not be attempted by an inexperienced hand, and never by any one from an unique specimen, for fear of any mischance. The process, however, is simple, and very valuable, when we desire an absolutely perfect intaglio impression of any coin or medal. The object to be copied is to be coated, on the side where we do not require action to take place, with grease, wax, varnish, or other non-conducting substance. A fine wire is to be passed round the rim, and then it is ready to be placed in the metallic solution. The adhesion of the air to the metal is of considerable importance in this case, and the metal should not be allowed to remain a single instant in the solution before the galvanic circuit is completed.

The obverse and reverse can be copied by two operations, or even both by one, taking care to grease the rim, so that the whole medal may not be confined by the new deposit. This operation gives us two moulds, one of either side of the coin or medal, in intaglio. By this process a copper medal or coin is liable to have its bronze removed, and, perhaps it is a good plan always to remove the bronze of the medal before immersion, by cleansing it with oil of turpentine; but a gold or silver one will not suffer the slightest injury. This mould may be used for making plaster-casts, sealing-wax impressions, or it may itself be again used as a mould to receive the galvanic precipitate, and we may thus obtain a very perfect relievo copy of the original.

(215.) Intaglios may be taken off coins or medals in lead, pewter, fusible metal, tin-foil, or silver-leaf in the manner

pointed out in the preceding books, and these intaglios are then to have a wire either soldered or placed in connection with them, when they will be ready for the reception of the metallic precipitation. (134, 135.)

(216.) The third method, however, is the one which should generally be adopted; for by non-conducting substances we can obtain most excellent moulds for receiving the precipitation. For coins, very small medals, and cameos, impressions in good sealing-wax are to be preferred by the amateur. (136.) These must have a fine wire melted into the wax, and be blackleaded, and then they are ready to be copied. (144.)

Larger medals may be copied in wax, stearine, bees'-wax, and rosin, or plaster of Paris. The plaster of Paris must be rendered non-absorbent by any of the processes given in a former book; tallow or spermaceti are best adapted, and from their being always at hand, are to be preferred; they are then to be blackleaded, when they may be placed in the solution. By either mode, perfectly sharp medals may be taken. To the workman who requires to make a large number of metallic impressions of coins, I would recommend the use of a square piece of plaster of any convenient size, say six inches each way, with impressions of medals as thick as he can put them. This might be easily managed by joining separate plaster moulds together till the size is obtained; this piece must be filled by the processes given before, blackleaded, and lastly, the metal is to be thrown down upon it. By this means he will obtain a sheet of coins, which he may either retain in that form, or by cutting them out may have each separately. The copper thrown down upon plaster is quite as perfect as the plaster-cast.

(217.) Having determined upon the process to be adopted, the operator has next to decide of what metal he will make his duplicate. To make a gold medal, perhaps the best solution on the whole would be the auro-cyanide; because it

allows the use of a great many kinds of metals as the negative pole. The *modus operandi* is similar in all respects to that of gilding; the only difference would be, that the deposit should be allowed to be a great deal thicker. I am doubtful whether non-conducting substances could be employed in this way.

A very useful mode of the application of gold would be, first, to throw down only a moderately thick layer, and then to fill up the deficiency by throwing down copper upon it. This, to the false coiner, might form a valuable piece of information; but is here mentioned to put people on their guard.

(218.) Silver electro-medallions require a more attentive description than gold ones, because the silver is of less value, and the process is easy to conduct. Silver electro-medallions may be made from every variety of mould—metallic (even iron) and non-metallic — that can be employed for electro-metallurgy generally.

For all metallic moulds but little difficulty occurs, except that adhesion must carefully be prevented. There is but little fear of adhesion of the new metal to iron, steel, or lead; but to copper, silver, and some other metals, there is some risk, from the corrosive nature of the solution of silver; perhaps, an infinitesimal layer of some greasy compound might with advantage be employed over the mould; that is, the smallest quantity of that substance might be rubbed over the mould, and then rubbed off as far as possible. The best solution of silver for these purposes is a strong solution of the argento-cyanide, though I have made medals from several other solutions. The single-battery process is the best adapted, conjoined with a silver positive pole about twice the size of the object to be copied.

Moulds made of non-conducting substances are also well adapted for the formation of silver electro-medallions. The object has only to be blackleaded and connected by a wire to

a battery about its own size, when the silver will gradually grow over the object, cover it, and become of any thickness the operator may require.

The quality of the metal thus reduced, if thrown down in the best reguline state, is very strong and elastic; so much so that but a thin deposit will suffice. Sometimes we are desirous of having the medal somewhat thicker, which may be accomplished in some cases (where we are desirous of being economical with our silver), by giving it a layer of copper at its back: the only circumstance of which we have to be careful is, to cause a proper adhesion between the two metals by making the surface of the silver chemically clean before immersion.

Silver medals are made as readily as copper ones, the only extra difficulty being first to get the pure silver; for every electro-metallurgist will not like to pay six shillings an ounce for this substance to make medals, independently of the cost of the mould and galvanic power derived from the battery, the latter, however, in this case, would not amount to a penny an ounce.

The surface of the silver is quite bright when it is removed from bright moulds; when removed from non-metallic moulds it is apt to be discoloured with plumbago: in which case the surface should be rubbed with emery or fine charcoal powder and a hard brush, and finally polished with a soft brush and rouge.

(219.) Medals may be made with great difficulty of platinum or palladium entirely, as in the cases just mentioned: or a duplicate cast of the medals may have an exterior of either of these metals, whilst the interior may consist of copper. The mould for these metals should consist of either gold, platinum, palladium, or silver. The solutions may be of any strength, although the operator will find the strongest the best adapted. See the general remarks on platinum, palladium, &c. (169—171.)

(220.) Copper is the metal of most importance to numis-

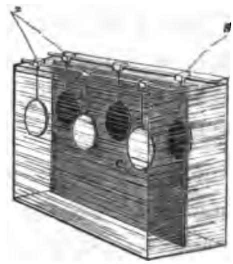
matists, and it will answer like silver both for metallic and non-metallic surfaces. The salt which may be employed for ordinary purposes is the sulphate; and when used for this purpose the solution should be more concentrated than when the reduced metal is required for the electrotype. A saturated solution of sulphate of copper, mixed with one-third of its measure of dilute sulphuric acid will answer admirably for general purposes.

(221.) In making electro-medallions, we must be cautious that no bubbles of air adhere to the mould, or are carried down into the solution when the mould is immersed. This is very apt to occur when the mould is very deep, as sometimes a series of air-bubbles may be observed adhering in the hair, the beard, or even the top of the nose; a circumstance which would not a little impair the features of the copy. To prevent any occurrence of this nature, the medal should be inspected after it has been in the solution a short time, and any bubble dispersed. If this be not attended to, the bubbles would become quite encased with copper, and a little hole be left.

(222.) The battery process is without doubt the best for making medals, especially if large; but the form of the precipitating trough must vary, according to the size and form of the medals to be made. For very large medals, say six inches in diameter, a common earthenware basin is the best. The medal is to be connected with a wire, and placed flat at the bottom of the vessel, and this wire is to be connected with the zinc of the battery. A piece of copper is now to be procured, which must be somewhat larger than the medal above which it is to be placed in the basin. The peculiar form of the basin will of course prevent the copper from descending upon the medal, a result which is carefully to be avoided. This copper is to be connected with the silver of the battery. The solution is then to be poured into the basin, when action will immediately commence; the cop-

per will be reduced upon the mould from the solution, and copper will be dissolved from the positive pole, to keep up the saturation of the fluid. It is always necessary to employ a battery sufficiently large; twice the surface of negative metal is most favourable for precipitation, though by following the principles already given, any sized battery may be employed. For many medals the battery process is greatly to be preferred. In this case the vertical precipitating-trough may be used. A piece of copper, connected with the silver of the battery, is placed in the middle of the trough; and on either side, as many medals may be suspended as can be arranged opposite to the copper; and these are all to be connected with the zinc of the battery. The advantage of this mode of proceeding over all others, is the facility given to the operator, either to remove or add one or more medals without any injury to the others; and eight, ten, twelve, twenty, or even a million if he pleases, may be made at once.

Fig. 35.



(223.) Although the battery process is generally to be preferred, yet it does not follow that it is the only mode capable of being adopted. Electro-coins and medallions may be made by any process described in the first chapter of the second book; as the zinc single-cell apparatus, the iron single-cell, the tin or lead single-cell apparatus will answer for this purpose, and if the objects happen not to be very large, the operator will not find it material what process he adopts. The only general rule to be adopted, in any case, is to take care that the sulphate of copper be concentrated, the positive metal sufficiently large, and the distance of the positive metal from the mould not too great. A little acid added to the sulphate of copper, will generally improve the quality of the reduced metal. (107—113.)

(224.) By any of these processes we can obtain a perfect cast from our mould; yet if the device on the mould be very deep, the deposit will not always take place favourably on the deepest parts. In these cases, when the medal is nearly completed, we may remove it from the solution, wipe it dry, and coat the parts most thickly covered with any non-conducting substance. The medal is then again to be placed in the solution, when the deficiencies will be soon filled up.

Great thickness of copper is not required for medals; for if it be as thick as a wafer, and of good quality, it will amply suffice. For most purposes it is of no advantage to have it thicker, and when we are desirous of strengthening the deposit, the back may be coated with sealing-wax. All these details must be regulated by the fancy of the operator, but by proper management the deposit obtained in twenty-four hours is quite sufficient for many purposes.

(225.) The last operation is the removal of the cast from the mould, which is attended with no great difficulty. We must be careful to remove any copper which embraces the mould at the edges, by placing the medal and mould in a vice, for which purpose a common wooden one answers admirably; then by filing the surplus metal from the edges, and pulling one from the other with moderate force, a separation will be effected.

Fig. 36.

When the duplicate has taken place upon the original medal itself, the adhesion will be very slight, if the precautions are taken which I have before detailed. Casts made from most non-conducting substances come off sometimes so readily that the mould is not the least injured. The adhesion indeed is greater when leaden moulds are used, yet, with care, the duplicate may be removed without much detriment to the mould, although it is generally slightly impaired. In every case some judgment is required to regulate the direction

in which we make the pulling force, according to the manner in which the prominent parts are arranged; for generally there is one way where the cast can be removed more easily than any other. To copper, &c., there need be no adhesion. (125.)

(226.) Copper electro-medallions may be gilt, plated, platinized, or coated with other metals, so that they may exactly resemble the original. The coating of foreign metal in this case ought to be very thin for fear of injuring the sharpness of the cast.

Electro-medallions may be readily made of zinc, by using a solution of sulphate of zinc, as neutral as possible, with a zinc positive pole, and connected with a battery of about the same size. Zinc electro-medallions possess no peculiar beauty. A metallic mould appears to be necessary in this case.

Electro-medallions might be formed of iron, by using a solution of chloride of iron, an iron positive pole, and a battery about the size of the negative metal.

Before we can understand the value of electro-metallurgy to the medallist, we must consider the processes he now uses to effect his object. Medals divide themselves naturally into two great classes: the first, which are cast and chased, that is, touched up afterwards, and the second division, which are made by a piece of metal being impressed with a steel die by a heavy blow given by an apparatus called a coining-press.

The first division of medals are first modelled in wax by the artist, from that wax impression a mould is made, and from that mould a cast in metal is procured. This cast is then touched up by the artist; but as each individual medal has to be touched up absolute identity is destroyed.

For this class of medals electro-metallurgy will undoubtedly supersede the old method; for the artist may take a plaster-cast from his original design, and make by electro-metallurgy a perfect fac-simile. The metal-cast he may then touch up and bring to great perfection; and he will be

enabled to obtain any number perfectly identical with the first which he has so laboriously perfected.

The second division of medals are those coined or made with a punch. The mode of proceeding in this case is more complex; but let us trace the processes necessary to make the current coin. In the first place, a likeness of the reigning sovereign is modelled by the artist in wax, which being approved of is finished as highly as possible in that material. The coins of the present reign are made by Wyon, and the beauty and high finish of the present five-pound pieces are a theme of universal admiration. As the workmanship of the coins during a whole reign depend entirely upon the skill of the artist, and as in centuries hence the state of the arts in our time will be inferred from the workmanship on our coins, how important is it to secure the first talents for that object; and having secured them to cherish them with a fostering care, and place within their reach every possible means that in any way, however remote, may contribute to the super-excellence of the work. The original sketch of the artist should always be copied in metal, either silver or copper, and carefully preserved; one copy being sent to the British Museum, another to Oxford, and a third kept at the Mint. By these means posterity would be enabled to have the identical likeness of each sovereign, that served as a model for the artist from which to make all his other works. A copy of such a sketch should always be placed under the foundation-stone of large buildings. To return to our subject—a plaster-cast is then taken from the wax mould, and a cast is generally made from it in iron, which is placed in a lathe, first employed in the French Mint: a blunt point passes from the centre of the object spirally over its entire surface, and is forced into all the depressions. This point communicates a similar motion to a cutting instrument, which cuts out an analogous impression on a piece of steel. This is repeated many times, by which at last a die is formed. This is re-

quired to be highly finished by the artist, who made the original model, so that the proper feeling and expression may be given to the die. This die is then hardened and used as a punch, by which another steel relievo is made by a very powerful press. After this second punch is formed, it is hardened and used to form the dies employed for coining. Pieces of metal of the exact size and weight of the coin are then prepared by a series of operations, and made very clean previous to coining. In the Mint, the pieces of metal are placed in a hopper, and one by one is let loose by mechanical contrivances and conveyed directly under the die, which is connected with a piston communicating with a vacuum. The pressure of air on the piston causes the die to descend with great force upon the object, and the piece of money is immediately thrown out coined. Such is the rapidity of the operation, that notwithstanding the immense outlay in the first instance for the apparatus and the expense of making dies, the cost of each coin is very far short of what would be incurred by electro-metallurgy, even if we were able to make perfect medals by that process.

However, the success of mechanics over electricity has its limit, for as soon as the medals begin to be larger, one blow will not suffice to bring up an impression; two or three are required, and between each blow the medal has to be placed in a furnace and annealed, as the compression of the first blow would incapacitate it for receiving a second with any advantage. The largest medal ever struck was the medal of Boulton, of which some impressions it is said had 300 blows. Here electricity begins to show its utility, and for all larger medals will for ever totally supersede every mode of casting. An immense medallion of the Duke of Wellington has lately been modelled by Palmer, and multiplied by his brother.

Hitherto we have been speaking of the comparative value of different modes of making original medals; but let us compare electro-medals with other casts used by numismatists. Now

there are only two substances much used for this purpose, and these are sulphur, and plaster of Paris. Formerly the obverse and reverse were arranged side by side on one piece of sulphur, wound round with paper gilt at the edge; latterly, however, it has been the fashion to make the cast exactly like the original, the obverse being on one side and the reverse on the other. Now the obverse and reverse of electro-medallions, after having been filed flat, can very readily be joined together with a little glue in such a way as to render it almost impossible to distinguish the point of junction; and it must be a matter of taste, whether the two sides should be kept separate or joined together. The great superiority of electro over other casts must be apparent to all, especially when we consider that the duplicate may be made exactly to resemble the original, not only in workmanship, but also in the nature of the metal of which it is composed. If the medals are gilt, or of gold, they will show to greatest advantage if arranged on a green ground; if silver, or plated, on a light blue; if bright copper, on a black; but if bronze, on a pale yellow ground.

As to the coins the electro-medallist should select for his operations; he should begin with the Jewish shekel from its historical associations; he should then copy the exquisite specimens of Macedonian coins, in which series those of the renowned Alexander and Philip of Macedon are contained. He should then select the extraordinary productions of the Syrian empire, the race of the Seleucidæ being much esteemed for their beauty. He may continue with Alexander's other generals, the Ptolemys, &c. In his road the electro-metallurgist must not neglect the Syracusan coins — the finest the world has ever produced — nor pass unnoticed the Carthaginian series, nor forget the relics of the former grandeur of the Greek Islands. The Roman empire next demands consideration, and the Cæsars must be copied. The medallist may copy a few more Roman medallions and coins after our Sa-

viour's time, and then pass to the early British, of which the Saxon should be the beginning of the sèries; after which, he should continue through the various reigns to modern times. Having completed such a series, the electro-medallist should arrange them in chronological and geographical order, and he will find that he has made an epitome of history, in which the progress of the arts may be traced through upwards of two thousand years. The high state of the arts in Greece, with their subsequent fall to the degradation into which the world had sunk under monkish dominion is striking, and their rise to the reign of the unfortunate Charles, about which period the Symons executed their splendid works, is remarkable. The slight vacillation of the numismatic art from that period to the present time may also be traced.

Those who prefer medals to coins, may select the finely cast and chaste medals of France and Italy, the medals of William and Mary, the Napoleon medals, those of the kings of France, and Wyon's latest productions.

The finest collection of coins and medals at the present time in the whole world, is at the British Museum, and when that establishment has an electro-cast of every other coin or medal that is known, either in copper-gilt, silver or bronze, so as to resemble the original, then indeed may Englishmen be proud of their national collection.

Where we desire electro-medallions to have a very perfect rim, it may be accomplished by winding round the mould a thin piece of sheet lead, copper, or such like metal, and allowing it to project about one-eighth of an inch beyond the edge, when it will be found, that on the completion of the process the electro-medallion will have a rim of that depth.

(227.) There are many eminent persons distinguished for their learning, their abilities, their public station, or, what is above all, their private virtues, a medallion of whom would be greatly esteemed by their friends. Now the expense of engraving a steel die in a first-rate manner, is such, that it

altogether precludes the idea in ordinary cases; but as soft substances can be copied by the galvanic process, the expense of obtaining a medallion in wax, when divided among thirty or forty persons, would surely not be a material object, and they would be thus enabled to possess a likeness of the person so much endeared to them. What a contrast would there be between the distribution of the portrait of a deceased and esteemed friend, and the unmeaning custom of giving a black and gold ring, simply bearing an inscription! How much better would the remembrance be perpetuated! for the ring is valued more frequently for its size and intrinsic worth, than for the remembrance it is intended to convey; and after having been worn for a year, is too frequently cast without remorse into the melting-pot. A copper or silver medal, on the contrary, no matter how beautiful its execution, would intrinsically be worth only a few pence, and frequently would be far more prized and taken care of by the possessor.

(228.) It is a great desideratum to be enabled to take a perfect coin or medal by electro-metallurgy, that is, one having both obverse and reverse; as yet this has not been obtained, and from my experiments it appears to me to be very difficult. The manner in which I have attempted to attain this object has been, to procure casts of both sides of a medal, and to place these in contact at the part of the plaster external to the impression, in such a manner that a distance intervened equal to the width of the coin; the inner surface of the plaster-casts were then black-leaded, and connected with the zinc of the battery, whilst the piece of copper to be dissolved was placed above a little hole left in the rim of the plaster-mould. In this position the moulds were connected with the silver of the battery; but the process, with me, did not succeed. I conceive, however, that it is possible, by this method, to make a thick medal with both obverse and reverse.

CHAPTER II.

ON COPYING SEALS, PLASTER CASTS, ETC.

Value of a seal, 229. Process for copying a seal, 230. Copper moulds from plaster medallions, 231. Quality of the reduced copper, 232.

(229.) In former times, when the art of writing was an extremely rare accomplishment, a seal was an instrument of great importance: it fulfilled the same purpose at the end of a conveyance or deed that is now accomplished by the written names of the parties; which even now, in reference to the ancient custom, are termed signatures. No business was performed without the seal, no corporation existed without this appendage. The extraordinary seal of Southwick, which required three separate dies to form one impression, is a good instance of the important functions of the seal; for the three parts being in the respective hands of three trustees, it required the concurrence of all, before a perfect impression could be made; and consequently, before any land or other property under the trust could be disposed of. Now the value of the seal is nearly lost, and in the great establishment where I lately resided, thousands of pounds hourly change hands without any such ceremony; a faint representation only of the seal being made by a black wafer, a bare relic of former customs.

(230.) Now that seals are nearly valueless, there can be no harm in describing the process for copying them. This is very simple; we first give them the thinnest film of black-lead, with a hard brush. If necessary, this may be aided by cautiously applying the most minute drop of spirits of wine,

but it should be avoided if possible; for the wax being soluble in alcohol, the seal is liable to more or less injury. A fine metallic wire is now to be heated over a candle, and the hot end placed in contact with the rim of the seal so that it may adhere. Care must be taken to apply a little plumbago round the point of insertion, that it may be continuous with the wire. It is then ready to be placed in the solution. This part of the operation is similar in all respects to that required for the moulds of coins. (220, 221, 222.)

After the seal is removed from the wax, it is usual to mount it by soldering it on to a piece of metal, and then to fix it on a turned handle for convenience of using.

Considerable care is required to effect this purpose, the seal must be first cleaned at the back with charcoal and water, and then dried. A little powdered rosin is sprinkled on the back, and the medal is then held in the flame of a spirit-lamp till the rosin begins to smoke, when a stick of soft solder is rubbed over it, and as soon as the solder adheres all over and fills up the hollows it is allowed to cool. The seal is then placed face downward on a cork, and with a file carefully reduced in thickness till the edge of the copper is apparent all round, but care must be taken to keep the two surfaces quite parallel. If the seal is very thick, the filling with solder may be dispensed with, as the copper in that case may safely itself be filed flat. A piece of metal, either copper or the alloy known as red gun metal (an alloy of copper and tin) is then prepared with a flat surface at one end sufficient to cover the seal, and with a socket at the other, to which a handle of either agate, ivory, ebony or other hard wood may be fixed. The flat part of the handle must be coated with a thin layer of solder, and that, together with the prepared surface of the seal sprinkled with a little rosin, when the two surfaces are placed in accurate contact, and then held in the flame of a spirit-lamp until the solder melts and unites the two, the edge is then to be carefully

filed and polished, and the face of the seal cleaned by charcoal and water. In those cases where the device is very deep it will not admit of being reduced perfectly flat, and in that case, the rim is filed to the same extent all round, and an indentation must be cut in the handle corresponding to the elevation at the back of the seal.

The largest seal, as the great seal of England, or the large seals of the bishops, may, in this way, be copied with ease; and the smallest are attended with no more difficulty. The operator must remember, that although he is at perfect liberty to copy the Chancellor's seal of the last reign, yet he would be liable to the utmost penalty of the law if he were to carry on his scientific proceedings upon the great seal of Her present Majesty. A letter received in the morning may be answered the next day, or even the same night, by a letter sealed with an electrotype impression of your friend's seal. If a relievo be required from a sealing-wax relievo, it may be obtained by a double electrotype operation, or by first making a plaster intaglio, and proceeding with that as for plaster generally. Seals may be made either in silver or copper, the processes for which are similar, in all respects, to that described for making electro-medallions.

(231.) Copper or silver moulds may be obtained of the utmost perfection, from plaster medallions. If we desire to take a copper mould or intaglio from a plaster relievo, we simply prepare the plaster by tallow, wax, or any other similar substance. We then carefully apply the black lead, and twist round the rim fine wire to connect it with the battery, after which it is ready to be placed in the metallic solution. The copper or silver copy is by these means as perfect as the plaster. When a relievo of a plaster medallion is desired, we may either electrotype the copper mould, obtained as before, or we may make a mould of white wax, having first filled the plaster with water. The wax mould is to be blackleaded, and must have a wire attached to it, before it is put into the solution.

The compound of bees'-wax and rosin may be used for the same purposes, its application being similar to white wax. The medal produced by any of these means is quite perfect, and the process is an excellent one; for it is neither attended with difficulty, nor does it require much labour, and is performed without the slightest detriment to the original plaster medallion. The whole difficulty attending the multiplication of works in plaster, is not the manufacture of the copper duplicate, but the trouble of obtaining the plaster itself perfect. It is singular, that every artist who uses this substance, considers that he is possessed of some secret; but in reality, the working in plaster is nothing but an art acquired by practice, and requires judgment in different cases; a full description of all the minutiæ requiring attention has been already detailed.

From a plaster cast we can obtain a stereotype mould, and from this a medallion in copper, silver, &c.; but few now would be inclined to follow this method when others are so well adapted. The apparatus and *modus operandi* are similar, in all respects, to that employed for the multiplication of coins and medals. (220.)—(222.)

(232.) The reduced metal, be it silver or copper, for the foregoing objects can be made of any texture that may suit it best. It may be either produced of the greatest flexibility, or of the most extreme hardness, by following the laws which we have laid down. A very hard medal, cameo, or seal, is best obtained by using a very strong solution, a single battery, and a large positive copper pole. It might be very useful for Bate's Anaglyptograph, an ingenious instrument, by which a correct engraving of any raised object can be executed. A point is passed over the medal at an angle of 45°, this communicating a motion to a diamond point. As the point passing over the medal is raised or depressed, the diamond point takes a corresponding curve, so that the lines ruled on the plate form certain curves, the effect of which is to give a

correct drawing of the medal. When a thin layer of black lead is used, the deposited copper will not in the slightest degree be discoloured by it, as the plumbago will always be taken into it, leaving none on the prepared plaster. If a very thick layer of black lead is employed the copper will be discoloured.

CHAPTER III.

ON THE MULTIPLICATION OF BRASSES.

Process for obtaining Duplicate Brasses, 233.

(233.) There is scarcely a church in the country which has not some curious old monument where characteristic likenesses of a whole family are engraved on a brass plate. To the Town Council of Yarmouth these relics were of so little interest that they condemned the whole collection from one church to be applied to the manufacture of standard weights for the use of the town. By antiquaries, however, these monuments are highly prized, and many would be delighted to possess a fac-simile of many of these objects. This may be accomplished by comparatively simple means. It is only necessary to take a cast of the brass in plaster of Paris, having previously oiled the brass; the plaster is to be well dried, and then soaked in tallow. A wire must now be passed round it, and black lead applied with a soft brush, when it is ready to be connected with the battery. Only moderately-sized brasses can be copied in this manner, for some are so large, as that of the Archbishop of York in Chigwell church, in Essex, or those in Westminster Abbey,

that they would require such large vessels as virtually to render the manufacture of a duplicate almost impossible.

The battery process is best suited for these purposes. A large piece of refuse copper must be employed for the positive pole, and it should be placed as near the plaster as possible. As a large surface of plaster is generally required to be copied, a large battery will be required, otherwise the strength of the metallic solution must be regulated to the power, and rendered much more dilute and acid.

A great taste has lately arisen for studying monumental brasses. The lover of these objects prowls over the country with a roll of lining paper in his hand, and a packet of heel-ball in his pocket; and wherever he finds one of these much-prized brasses, he places the paper over it, and rubs the surface of the paper with heal-ball, which blackens it, except at those parts immediately over the incised lines. This mode decidedly gives the clearest impression, but some antiquarians prefer a mixture of linseed oil and black-lead, about the consistence of mustard, which they apply to tissue paper with a leathern rubber. For further particulars relating to these curious matters, the student must refer to works peculiarly devoted to these remains, but especially to those exquisitely beautiful and accurate illustrations of monumental brasses by the Wallers; a work already in the library of every person having the slightest pretensions to a knowledge of the antiquities of Great Britain.

CHAPTER IV.

ON MAKING DIES FROM EMBOSSED SURFACES.

On metallic reverses from raised surfaces by galvanic agency, 234. Peculiarities of dies made from paper, 235.

(234.) ALL embossed surfaces may be copied with facility, whether they consist of paper or any other substance. They must be first rendered non-absorbent by oil, varnish, or wax, according to the thickness of the texture; linseed oil perhaps is to be preferred for paper. It must be allowed to dry before the black-lead is applied to make it ready for the solution.

(235.) Dies made from paper generally exhibit a slightly dented appearance in the smooth parts, from the little projecting points of the paper having been copied. This, it is said, disappears after many impressions have been printed. Doubtless the attention of the commissioners of stamps and taxes has been drawn to the fact, that the stamps can with great ease be copied by the electro-metallurgist; but it must remain with them to consider whether any attention to the subject is requisite.

A hard copper die formed from a sealing-wax impression would in all probability be applicable to the formation of stamped wafers now so much in use.

CHAPTER V.

ON THE MANUFACTURE OF MOULDS FROM FRUITS, VEGETABLES, ETC.

On making moulds from vegetable substances, 236. Chantrey's method, 237.

(236.) In a former book, means were adverted to for coating various kinds of fruit, vegetables, and leaves with metallic copper, having first black-leaded them. (207.) By simply carrying on the process until a thick deposit be obtained, instead of merely coating the object, a mould will be obtained for any purpose required. A cast thus taken of a leaf, for instance, that of a Morel cherry, baffles all description. The copy is absolutely perfect; every fibre and nerve, in fact the minutest part, is cast in copper with the utmost fidelity; and in the same way the surface of fruit may be correctly copied, so that every excrescence or depression, however minute, will be as apparent as in the original.

(237.) Sir Francis Chantrey had a very ingenious, though a troublesome and complicated, method of obtaining a cast of leaves or sprigs of trees; he takes the finest river sift, ground up, and encloses the leaves and sprigs in it; the whole is then dried and thoroughly baked, by which process the wood is carbonized; a strong blast of air is then sent through the apertures, which removes the carbon and leaves a cast of the object, and that serves as a mould, into which he pours his melted copper. The same end might be attained in some cases far more readily by the galvanic current.

Every vegetable and animal substance whatever, which will remain undecomposed in the solution of copper for a few hours, can have a metallic mould made from it. For nearly all these cases the battery apparatus, similar to that used for medals, is the best.

CHAPTER VI.

ON THE APPLICATION OF ELECTRO-METALLURGY TO SCULPTURE AND OTHER PURPOSES.

(238.) Unfortunately the British public have nearly ceased to patronize British sculpture, otherwise electro-metallurgy would be a valuable assistant to that art. The sculptor first makes his model in clay, from which he takes a cast in plaster, and this again serves as a mould, into which he pours his fused metal. This latter proceeding is attended with much trouble, and not unfrequently with great danger from a risk of explosion. The metallic cast when made is by no means perfect, as it requires much labour to finish it.

The electro-metallurgist could obtain a far more perfect cast at once, by simply preparing his plaster, black-leading it, and placing it in the solution of sulphate of copper. A wire in contact with the black lead must communicate with the zinc of the battery, whilst the sheet of copper to be dissolved should communicate with the silver.

(239.) For very large designs, an inconveniently large vessel would be required; to obviate this difficulty, the mould, provided it be hollow, might have the separate pieces of which it is made so joined together by wax or grease that itself should form the vessel to contain the liquid. Very large batteries ought to be employed by the sculptor, and rather a dilute solution; because, in all probability, the size of the

battery will not be proportionate to the immense surface exposed in even a moderately-sized design. The piece of copper forming the positive plate should be as large and as close to the plaster mould as it can be placed, in order that as little impediment as possible may be afforded to the passage of the current.

(240.) The copper may be of any thickness; and its strength and thickness may be regulated as required in different parts, by increasing or diminishing the distance between the various parts of the plaster and the positive plate of copper. The relative cost of this method of making a bronze figure, and that of the plan now in use, is, perhaps, difficult to estimate accurately. By the old plan a bronze figure costs the value of the copper and the coals required for its fusion, besides the labour requisite to render the metal cast perfect afterwards. By the galvanic method it would cost the value of the copper, + the value of an equal weight of amalgamated zinc, + the cost of the labour required to work the batteries − the value of the sulphate of zinc formed. From the above statements, a rough idea only can be formed of the relative cost of these two methods in practice, and it can only be determined with certainty by very large operations.

It certainly must become a great temptation to the lovers of science to construct a duplicate, by electro-metallurgy, of the famous Wellington statue now in progress by Wyatt, the dimensions of which may be at once understood when it is mentioned, that a tall man without removing his hat may ride on a horse of average height under the belly of the colossal figure, and still have two or three inches to spare.

The original it is calculated will weigh when completed, about fifty tons, but probably an electro cast of about two tons could be made sufficiently strong by being suspended by an internal frame-work of iron. Such a cast might perhaps

be made for about four or five thousand pounds, including labour of every description requisite to make it quite perfect. Can such a temptation exist without being acted upon? Is there no town but London under sufficient obligations to the immortal duke as not to record its sense of them. A statue such as that under consideration made by electro-metallurgy would be a glorious work. Admirers of the arts wake up! patrons step forth! science lend your aid, manufacturers assist, and all grateful hearts subscribe! Success will crown the attempt, and the work will be esteemed the wonder of the world!

Chaterton, who executes exquisite cutting of ivory by means of a peculiar machine, exhibited last winter at the various scientific soirées a skull bust prepared by electro-metallurgy. His *modus operandi* was to form a cast of the head, and coat it with copper, and then to remove the interior cast. In the copper mould thus obtained, he deposited a copper reverse; but the whole operation is subject necessarily to considerable difficulties requiring continual watching. The bust he exhibited was very perfect, but the exact means he used have not been published. As far as regards the electro-metallurgical process, the solution, positive pole, &c., must be regulated by the principles so fully detailed in former parts of the work.

(241.) Before bringing this book to a conclusion, I may mention that the application of electro-metallurgy, or the art of working in metals by the galvanic fluid, is not confined to the foregoing subjects; for every kind of object which can possibly be made in copper by any other method can also be made by electricity. With regard to the use of other metals for the like purpose, they can in some instances be employed; but still, the application of the galvanic fluid to the working of these must be limited, because the intrinsic value of many is so great as to preclude their general use; whilst

the value of others is so trifling as to render their application of little value.

As a general rule, all articles of tin, lead, iron, and zinc are infinitely better, and far more cheaply made by the present mechanical processes than they could be by electro-metallurgy. I do not pretend to say that there may not be some particular cases where the pure metal obtained by the latter process might be preferred to the impure metal. Pure iron might be valuable, pure zinc might be useful, but, for all manufacturing purposes, there is but little doubt that the cheapness, ease, and, above all, the capability which mechanics possess of an unlimited production of articles by the steam-engine gives a vast preponderance in its favour, especially when we consider the mind continually required to superintend and direct voltaic processes.

For articles of copper, the benefits of electro-metallurgy do not manifest themselves whenever the cost of the workmanship is not equal to the cost of the voltaic reduction, and whenever the object can be made by pure mechanical means, as the latter in these cases are mostly to be preferred to chemical means. As soon, however, as the cost of the materials and labour exceed those required by the chemical, then does electro-metallurgy begin to be advantageous, and the multiplication of all elaborate and highly-finished articles should be effected by the latter process. In a former part of this work data for ascertaining the expense of the various processes, comprising electro-metallurgy, have been quite sufficiently considered. Although, however, throughout this work the relative cost of processes has been continually discussed, let me once again strongly urge the manufacturer to pause before he introduces electro-metallurgy and substitutes it for former modes of manufacture. Excellence and economy are the only circumstances that he has to regard in a business point of view; and he has no right to consider the beauty of any particular process, or to be allured to apply electro-metallurgy

for purposes not suitable to it, by the demi-magical phenomenon of an old worn-out nail and a dissolved penny-piece being capable after a few hours' patience to form a duplicate of a work of art which required years for its first execution.

Attempts have indeed been made to make copper tubes by electro-metallurgy, and also saucepans and similar vessels, but there is no doubt that those who practised this mode must have been ignorant of the relative expense of the processes. However, in this case, as in others, it is possible that tubes of peculiar curves might sometimes be made profitably by electro-metallurgy, and that the absence of soldering might be turned occasionally to advantage.

Electro-metallurgy offers means for the multiplication of polished surfaces, but its benefit is confined to particular cases, as highly-burnished surfaces cannot be so perfectly multiplied, because if those surfaces are absolutely clean adhesion would take place, and if the air adheres to the originals a slight spotted appearance termed "a curd" is noticed, which would seem to be an irregularity in the thickness of the film of air. Although burnished surfaces cannot be absolutely and perfectly multiplied, yet for many practical purposes the process may be effected. The formation of duplicates of specula must be regulated by the preceding observations, for it would be requisite always to finish the duplicate by burnishing. All such delicate processes should never be attempted till experience has taught the operator how to overcome the difficulties likely to occur.

With regard to the manufacture of silver articles by electro-metallurgy, the preceding observations equally apply. The manufacture of silver spoons and forks by the present process is effected so cheaply as to leave no shadow of doubt that it is infinitely to be preferred to electro-metallurgy. Very elaborate articles of which duplicates are required, might perhaps be advantageously made by electricity, and it is almost needless again to mention that the silver might be strengthened

with layers of copper, should ever such process be required. One objection to electro-metallurgy for these purposes is the necessity for the employment of pure silver.

(242.) To workers of gold electro-metallurgy promises to be occasionally of value; for after having once procured a mould, he could obtain the most elaborate devices; but still, in buying manufactured articles of gold, the intrinsic value of this metal is so great that the workmanship forms frequently but a small part, or otherwise electro-metallurgy might be of importance to the goldsmith.

The dentist requires for artificial teeth an exact cast of the mouth in gold, platinum, or palladium. Now the cost of the manufacture of this is so expensive, that many are prevented from availing themselves of these valuable appendages. It is absolutely necessary that the gold should fit very accurately, or else the possessor is not able to use them. Electro-metallurgy might, perhaps, be brought to aid the mechanic in this matter, but the operator must recollect that notwithstanding the scientific principles detailed in this work, considerable skill in the manipulation would be required, especially as it is necessary that the metal should be of the utmost tenacity and firmness.

(243.) Even to the surgeon, electro-metallurgy appears likely in some cases to be useful; for when he is desirous of exerting constant pressure on any part, or of confining any part in a particular position, he can make a copper instrument exactly to suit any individual case by first taking a cast in plaster of Paris, or, which in some cases will be found more useful, by a piece of gummed sheeting. At present no case has occurred in my own practice where such an application of electro-metallurgy has been required; but I have seen cases of club-foot, where doubtless a metallic mould might have been applied with great benefit to the patient. With regard to metallic splints, perhaps in some cases they might be used with great advantage, but as a general rule

those made of the moulding tablets (which I have described in the Medical Gazette) are more applicable. By a proper use of splints made of these moulding tablets many cases of broken limbs have occurred where the patients have been enabled to leave their beds and enjoy the comforts of the external air within three or four days of the accident. For these purposes splints made of my moulding tablets would, from their lightness, be much preferable to metallic splints, for though they may be made to take a perfect cast of the face, they yet set so firm and hard as to bear a very severe blow without accident.

To the geologist electro-metallurgy is not without its interest, for, independently of the rationale which it affords of the veins of metals embosomed in the earth, it gives the means of obtaining in copper casts of any fossil which will remain unacted upon in the metallic solution. If the solution is acid, of course it will be unsuitable for any strata containing carbonate of lime; but then, by first taking an impression in plaster, a metallic reverse can be taken from it, which will be a perfect fac-simile in metal of the original. These metallic casts are preferable to any other kind of duplicate, because they occupy less bulk, are lighter, less destructible and fragile than any other material.

Electro-metallurgy is now brought to such perfection, that a copper cast of tenacious metal can be made of any size or form; and it may be even painted to resemble the object it is intended to imitate. All other materials, as far as possible, should be discarded from our museums, as for nearly all purposes the copper is entitled to a decided preference.

The architect should always bear in mind the powers with which electro-metallurgy furnishes him. By it he will be enabled to introduce at but moderate expense, relievos, ornaments, statues, friezes, &c., &c., into the composition of his building. In the construction of churches electro-metallurgy, if used rightly, is capable of adding great effect; for altar-

pieces, chancel-skreens, organ fronts, &c., may be made of various metals. If electro-metallurgy, only in a slight degree, should cause us to return to the splendour with which Solomon considered that buildings dedicated to worship should be constructed, then, indeed, will all who have assisted in developing its laws and facilitating its practical application be proud; for there is no national disgrace more to be deplored, than that buildings erected for dancing, feasting, or debauchery should be fitted with all the embellishments which modern science has so abundantly supplied, whilst too frequently buildings not sufficiently excellent to be used as kennels for the hounds of the nobility are thought amply splendid for consecration to the worship of the Almighty!

BOOK THE FIFTH.

ON THE ELECTROTYPE.

CHAPTER I.

ON THE MULTIPLICATION OF TYPE.

The mode of printing books, 244. On stereotyping, 245. On Electrotyping the type, 246.

(244.) THE ordinary type, such as this work is printed with, has each letter separately cast of a particular alloy; these letters when combined together form words; again, a number of words form a paragraph—a series of paragraphs a chapter—a number of chapters a book—and lastly, several books form this volume. Most works are printed in parts; thus, whilst I am writing this chapter the second book is completely printed, and the types distributed, whilst the proof of the third is lying on my desk to receive such alterations as may occur to me. Now the electrotype would be of no value to the printer in this case, for the same type which is used for the first part of this work, will be again used for the last, and even after the whole is printed, will be very little impaired.

(245.) With books which have a very large circulation, as the Bible or Prayer-book, and where no changes are required in the matter for a series of years, it is usual, after the work

is completely set up in type, to take a stereotype copy of it. A plaster mould of the type is first obtained, which is thoroughly baked in an oven, and from this a metallic cast in stereotype metal is made, which is a copy of the original. The duplicate thus obtained is slightly impaired by the injury which the plaster cast receives in the furnace, otherwise it has advantages over the type; for every stereotype page is in one piece, whilst the type is made up of as many different pieces as there are letters, besides numerous pieces termed leads, &c. The process of stereotyping is cheaply effected, but the electrotype may be made more perfect.

(246.) To procure an electrotype copy from a page of type, we have to take an intaglio impression from the type, which is most conveniently effected by making a plaster cast, and afterwards rendering it non-absorbent, or we may take it in white wax; the intaglio impression must be black-leaded and placed in the solution to receive the deposit of copper. The horizontal apparatus is much to be preferred in this case, and great care must be taken to disperse air-bubbles. A moderately thin layer of copper would suffice, if it were backed with solder, type, or some such analogous alloy. This process is only likely to be useful for Bibles, or works that have a large circulation; and, probably, might be found to wear longer and print better than the usual stereotype metal; but at present we have no experience on that matter; though there is but little doubt that for these purposes electro-metallurgy will eventually be preferred.

CHAPTER II.

ON THE MULTIPLICATION OF PLAIN COPPER PLATES.

The preparation of plain copper plates, 247. The electrotype plates, 248. Process for their manufacture, 249. Manipulation of the battery, 250. Precipitating trough, 251. Temperature, 252. Positive pole, 253. Regulation of the texture of the copper, 254. Single-cell apparatus, 255. Time required for the process, 256. Removal of the plate, 257. Mode of preparing the plate for engravers, 258. Economy in the manufactory, 259. Expense of the plate, 260.

(247.) THE application of the electrotype to the various departments of engraving, is of the greatest importance, and the new field opened in this branch alone, is very extensive. Engravings generally are made upon copper plates, which have undergone a tedious preparation. The copper which is to be employed for this purpose should be as pure as possible; it has first to be rolled to a certain thickness, after which it passes into the hands of the copper-plate maker. He carefully examines the plate, and picks out any little piece of foreign metal he may chance to perceive, and then fills up the gap by dexterously hammering around it, so that he draws the neighbouring copper over the hollow. The plate is then well hammered, and receives a rough polish by charcoal. The price of a plate so manufactured, is worth from two shillings and sixpence to three shillings and sixpence per pound.

(248.) This copper-plate is by no means pure, as it generally contains tin and other metals, which render the engraving sometimes difficult, and the etching very uncertain. To

obviate these faults we make an electrotype plate on one of the prepared copper-plates, and as the metal of this is absolutely pure, it is found to be far better adapted for the purposes of the engraver. This duplicate plate possesses a similar surface to the original, and may therefore be at once used; but it is found better to hammer the duplicate, and prepare it with charcoal, as that greatly improves it by making it more elastic; and it is the opinion of one of the first plate makers in this city that the hammered plate will work as well as steel.

On one of these electrotype plates hammered and prepared as plates ordinarily are for engraving, Mr. Palmer had various specimens of art executed. First, the platemaker's opinion was taken of it, and he decided that it was vastly superior to the common copper; here we may remark, that many persons have doubted whether the electrotype copper would bear hammering; now this plate was thus prepared. The plate was then sent to a letter-writer, to receive a specimen of this species of engraving, as well as to have his opinion of it; he stated, that the quality of the copper was such that much less labour was required for the process which it had to undergo. It was then sent to an etcher, and he found it greatly superior to ordinary copperplates; for the nitric acid bit with the utmost uniformity on account of the purity of the copper. A specimen of machine-ruling, rose-engine turning, and medal-ruling by Bate's patent anaglyptograph was then executed, and the opinion of all the artists concerned in the work was similar; for the superiority of using pure copper over the ordinary copper, which is usually contaminated with other metals and charcoal, was apparent to all.

(249.) The exact process by which these electrotype plates may be prepared, is very simple. The plain plate on which the deposit is to take place, is to have a flat band soldered on its back, in order that efficient connexion may be made with

the zinc of the battery. The heat necessary to effect this, drives off the air which infilms the metal, so that if it were placed at once in the solution of sulphate of copper the two plates would stand a very fair chance of adhering to each other. To prevent this serious evil, the plate which has been soldered ought to be placed in a cold place for twenty-four or more hours, which will enable it to regain a second time its film of air. Those who are not skilful in soldering metals, may simply place a wire or piece of metal in contact with the back of the plate, as that connection will be amply sufficient. Every part of the plate which is not intended to receive the deposit, must be covered with tallow, wax, or any other non-conducting substance.

(250.) Having thus prepared the plate, a platinized silver battery, which exposes about twice the surface of negative metal, is to be charged with dilute sulphuric acid, consisting of about one pint of strong sulphuric acid in two gallons of water. By using the acid thus diluted, the risk of much local action is materially lessened, and for the same reason the acid should never be poured into the battery till it is quite cold. The best form of battery for these purposes is fig. 4, p. 26. The silver has a binding screw soldered to it, and a piece of wood is fixed on its upper part. The zinc is placed on each side of the silver, and consists simply of two strips which have no solder attached to them, but are connected to each other, and to a binding screw by a large screw, which embraces at once the two zinc plates and intervening piece of wood fastened on to the silver. This very ingenious arrangement appears to have been devised by the instrument-maker, from a necessity which the manufacturer experienced of repeatedly adding a new zinc as soon as the former was dissolved.

(251.) The precipitating trough may be either the horizontal or vertical. The vertical trough is an oblong wooden vessel cemented in the interior; on one side the plate to be multiplied is placed, on the other a piece of copper to be dis-

solved. (fig. 12, p. 68.) The horizontal trough is a shallow, square vessel, on the bottom of which the plate to be copied is placed, and half an inch above it, the copper to be dissolved. (fig. 15, p. 76.) It is necessary to place the negative plate underneath, or else the uniform strength of the solution would not be preserved, but a mass of crystals deposited at the bottom of the vessel. The first apparatus is best adapted for a slow precipitation and small plates, but the last for a rapid deposition of the metal and large plates.

Whichever process be employed, the trough must be filled with a solution of sulphate of copper of a strength suitable to the power of the battery. If one battery be used, it should consist of a saturated solution of sulphate of copper, diluted with rather more than one third of dilute sulphuric acid. A solution of nitrate of copper may be employed of about one pound to the pint and a half, which will allow the deposit to take place more quickly. A nearly saturated solution of sulphate or nitrate of copper may be used, if a series of four or five batteries be employed, or the solution be kept at a high temperature. It is advisable to place the plate in a neutral solution at first, and afterwards, when it is slightly covered, in the acidulated solution, in order that the film of air may not be removed.

(252.) Where practicable, the solution should always be kept at a moderately high temperature; as by that means the deposit will take place far more rapidly, and the copper will be more elastic. The reader must not confound the property of elasticity with flexibility, although this is an error very commonly made. Flexibility is the property which bodies possess of being easily bent; elasticity is the power which bodies have, of returning to their former shape after they have been bent. The flexibility of any metal is a property very readily obtained by the laws pointed out; elasticity, on the other hand, is a property more difficult for the electro-metallurgist to obtain than any other.

(253.) Having filled the trough with the liquid, we take a piece of copper the same size as the plate, and connect it by a wire to the silver of the battery. We have now the battery charged, the precipitating trough filled with its solution, and the piece of copper to be dissolved placed in the precipitating trough, and connected with the silver. Having proceeded thus far, the wire, soldered on to the copper plate on which the new deposit is to take place, must be connected with the zinc of the battery, and the operator must be particularly careful that dropping the copper plate into the precipitating trough is the last operation for completing the galvanic circuit, as immediately a precipitate of pure copper commences. This does not adhere to the copper plate, because it is not in contact with it, for a thin layer of atmospheric air is interposed between the two.

(254.) Having put the apparatus in action, the operator must regulate the quantity of electricity passing, by approximating or increasing the distance between the two poles in the precipitating trough, according as he may require differences of texture in his copper; for the reduced metal may be obtained as soft as lead, nearly as hard as steel, or of any intermediate quality; the copper should neither be too crystalline nor too flexible, but should be of a texture intermediate between both extremes. The laws regulating these points have been sufficiently dwelt upon above. The apparatus will require no material alteration for two or three days, and then the acid in the battery should be changed, and the zincs, if necessary, renewed. The piece of copper forming the positive pole should always be examined, and removed if necessary. A plate should not be allowed to remain inactive in a neutral solution for any considerable time whilst it is being made, as in that case the reduced copper is apt to be in layers.

(255.) The single-cell apparatus is not at all well adapted for making copper plates, because it is impossible to regu-

late with accuracy the quantity of electricity to the strength of the solution. In fact, all the largest and most perfect plates hitherto made have been produced by the battery apparatus.

(256.) The time necessary for the complete formation of a plate, varies according to the thickness of the copper required, the ease with which the solution suffers decomposition, the power of the battery, and the distance between the plates in the decomposition cell, or precipitating trough. The shortest time in which it could possibly be made, is from twenty-four to thirty-six hours; but with a single cell and dilute acid it ordinarily takes a week, or even more; the texture of the copper, however, in both cases, may be made similar. The only limit which is afforded to the rapidity of the process, is the cupreous salt. As the nitrate is the most soluble salt of copper, we never can obtain a plate more rapidly than the strength of its solution will allow.

(257.) Having made the plate, we have now to take it off; and for this purpose, any copper embracing the edge of the original plate is to be removed; after which, the operator without any difficulty may separate the two plates, for provided he has followed exactly the directions which I have before given for insuring a film of air on the plate, not the slightest adhesion will exist.

(258.) A plain copper plate is thus made, which can be used at once by the engraver, or it may be hammered and rubbed with charcoal, as copper plates ordinarily are. Duplicate copper plates have been made from another similar plate, but we can obtain a copper plate from smooth substances, which are not capable of being acted upon by the fluid; thus, smooth white wax, sealing wax, or smooth plaster of Paris, will receive the deposit after they have been black-leaded.

(259.) The manufacturer who makes electrotype plates in an extensive way, must endeavour to lessen the expense of the process by every possible means. In the first place, he must

recollect that the mercury used for the amalgamation of the zinc is not at all acted upon, but that when all the zinc is dissolved, it remains upon the fine particles of foreign metals which the zinc contained. He should carefully preserve this mass, as well as all the fragments which have been left; the mercury may in great part be separated from this, by enclosing the mass in wash-leather and squeezing it; the rest may then be obtained by distilling the residue. Theoretically, the operator ought to regain as much mercury as he originally employed; but practically, he will always suffer a certain loss.

The sulphate of zinc left in the battery after it has been exhausted is absolutely pure; and therefore the solution may be evaporated and the crystals of the sulphate of zinc obtained; or the metal may be converted into a carbonate, for which there is great demand in the arts. The deposited copper in the same manner is also pure, and, therefore, all the clippings should be preserved for the purpose of alloying gold, as it is necessary to have a perfectly pure metal for that purpose.

Those who manufacture a great number of plates and to whom time is not an object in their proceedings, can adopt a peculiar form of battery. The battery should be large, and should be connected, not to one precipitating trough alone, but to a series arranged exactly as a compound battery; thus, if twenty troughs were arranged and connected with the battery, they would obtain twenty pounds of copper for one pound of zinc dissolved. The solution of sulphate of copper in each cell should be rather more dilute, and be much more acid, than when a single trough is employed, and the positive copper-plate and negative plate of each cell should be of the same size. The large battery, in this case, is not attended with more expense than a small one; for to do any given amount of work, as much zinc would be dissolved in a battery made of a silver thimble, as in one exposing a sur-

face of negative metal equal to the surface of the whole of Europe! The rationale of this apparent paradox is explicable by the important law, that "In every cell the amount of chemical action is the same;" one battery will therefore, for every pound of zinc dissolved, precipitate one pound of copper in each precipitating trough, so that the number of precipitating troughs, arranged as a compound series, will give the number of pounds of copper thrown down for each pound of zinc dissolved. If we consult the equations given in a former part of this work, we shall find that it is of no use increasing our batteries above a certain size, and therefore we must take care to lessen the resistances in all our troughs.

(260.) In this great commercial city it is useless to mention the excellence of the process, unless, at the same time, some idea be given of the expense attending its adoption. This, with a single battery and precipitating trough, will be, first, the intrinsic value of the copper, say one shilling and two pence for each pound, plus an equivalent of amalgamated zinc one shilling, plus some zinc lost by local action, plus sulphuric acid, say fourpence, equal to two shillings and sixpence a pound for the bare cost of the materials. To this, labour, time, house rent, and profit are to be added, which will increase, at present, the price to one sovereign per pound of copper; though doubtless the expense will be diminished as the demand increases. For plain plates persons would hardly like to give this price, unless an engraver were about to execute a very splendid subject, and then perhaps it would be fully worth his while to go to the extra expense, from the superiority of his material.

CHAPTER III.

ON COPYING ENGRAVED COPPER-PLATES.

Engraved copper-plates, 261. Design on the plates, 262. Various kinds of engraving, 263. Uses of engraved plates, 264.—For the potteries, 265.—For calico printers, 266.

(261.) Engraved copper-plates are not more difficult to copy than plain ones. A plate possessing the most elaborate design, the most brilliant conception, the finest execution, the most delicate workmanship, in fact everything calculated to render a plate valuable, can be copied with the same readiness, the same fidelity, the same ease, as the plate without any workmanship at all; because the deposit of new metal takes place in such a way that an exact cast is made in both instances.

(262.) The design of all engraved copper plates is in intaglio or depressed below the surface, and the problem is to obtain a duplicate in a similar state. To effect this, a reverse of the plate must first be taken in relief. This may be done in various ways. In the first place, a relievo may be obtained in copper, precisely in the same way as a duplicate plain plate. (249—257.) This is the most perfect process, and should always be adopted for very delicate designs.

An impression of a plate may be made on perfectly clean lead, by placing the lead on a printing press with an iron bottom, and then placing the engraved plate upon the top of it. The two are then to be run through the press, exactly in the same way as an ordinary print is taken off. In this operation, if the lead be placed underneath, a very perfect impression

may be effected; but the upper plate is sure to become bent, which is a disadvantage. If the copper plate is placed underneath, that will receive no injury, but the lead will be curled in a similar manner. Now on considering these facts it occurred to me, that if a third plate above the other two were employed, there would be no curling, and upon the experiment being tried two or three times, my expectations were realized, for neither lead nor copper were curled to any amount. The mode in which I directed the experiments to be performed, was to place smooth lead at the bottom, then the copper plate upon this, and lastly a third metallic plate at the top, which became curled by the process. A great disadvantage, however, in the use of lead for these purposes is, that the metal is liable to stretch unequally.

A perfect mould may be taken from an engraved plate in white wax, but it requires some practice to copy a large plate. The white wax must be black-leaded, and then placed in the solution. Plaster of Paris may also be used to take a relievo impression, and the stereotypers are very excellent hands at using this substance; but although I have made duplicate copper plates from plaster, I am afraid that it will scarcely be thought sufficiently perfect to be used for the electrotype, in all cases. The plaster must be very carefully filled by the methods I have elsewhere detailed, and after the application of the black lead it may be placed in the solution.

Having by any one of these methods taken a relievo impression, a reverse is again to be taken, in a manner similar to that pointed out for copying a plain plate. The film of air, which substances acquire by exposure to the atmosphere, must be obtained before the object is placed in the solution. (249—257.)

(263.) The back of the reduced plate will be always more or less rough, which is to be filed smooth before a print is taken from it. Sometimes, when the plate is thin, a second plate of tin or iron is soldered into the back; but the unequal

expansion of the metals, when heated, is liable to be attended with inconvenience. By the use of this artificial back, however, we can employ the crystalline copper, which is so intensely hard, that in all probability the plate would last much longer.

The front of the plate is liable to exhibit over its otherwise polished surface an appearance in copper, as if the slightest breath, or film, covered the surface. This has been technically termed "the curd," and is instantly removed by the copper-plate maker by a few slight touches with his charcoal. To account for this curd will not require much thought when we mention, that if the operator simply place his finger on a polished plate the copper reduced upon it would have precisely similar marks; and I have seen it exhibit every line of the finger, and even the opening of each perspiratory duct.

(264.) Those not much acquainted with engraving will perhaps be astonished at the various means which artists employ to execute an engraving. They may however be divided generally into three heads. The first contains those cases where the design is made by instruments of various kinds, as gravers, dry points, &c. In the second, the device is obtained by acting partially on the plate by acids capable of dissolving it, or in fact by biting out the lines or figure of which the engraving is constituted. The third kind, where the surface of a plate is uniformly raised up by an instrument, in such a way that it prints all over perfectly black, in which state it is ready for the engraver. By burnishing the plate all the asperities are rubbed off, and that portion thus treated prints whiter: so that by regulating the degree of burnishing the different effects of light and shade are produced, which constitute the engraving. This is called mezzotinto. It is far cheaper than the line engraving, and is now much in vogue. Each of these three classes of engraving has been copied by Mr. Palmer and others, with the utmost

fidelity, so that the application of the electrotype may be said to meet every case for which it is likely to be required.

(265.) Engraved plates were not employed till the fourteenth century, but now their uses are manifold. To hand down to posterity, and to diffuse among the multitude, copies of the choicest pictures and other works of art, are their most prominent applications. To perpetuate the resemblance, and to distribute the portraits of the great, the good, and the beloved, are other important uses. With these the public are most acquainted, but they do not constitute a tithe of the purposes for which engraved plates are required. The great consumption now for these plates is at the potteries; for almost every common dinner-service, or every piece of pottery, has its design given by a copper plate. The device is deeply cut in the copper, and then it is printed on a piece of thin paper; but the impression is printed with a composition of arsenite of cobalt instead of the ordinary ink. The paper is then pressed upon the pottery plate before it is glazed, in order that the ink may adhere to it; after which the paper is carefully washed off. The pottery plate is next glazed, and is then ready for use.

The most unmeaning devices are printed on the plates, and the willow and other similar patterns certainly exhibit no great beauty of design. Our common pottery-ware, however, is the envy of every foreign country, for nowhere but in Britain have they ever been able to make common earthenware with any degree of perfection. The electrotype promises to materially improve the patterns of our otherwise unrivalled pottery, for the expense of engraving valuable plates has been hitherto such, that on account of the small number of copies they will afterwards print their application has been necessarily prevented. Now if a plate cost originally a thousand guineas, an infinite number of duplicates could be taken from it by the electrotype, and in this way the expense of every common dinner plate would be the same, whether the ordinary blue

and white service were used, or plates and dishes were embellished with copies of our finest works of art, the most exquisite scenes of nature, the most elaborate machinations of fancy, or the most intricate specimens of execution. Before long I trust that the silly devices we have at present in use, will be changed for more elegant and highly-finished drawings.

(266.) A second extensive application of copper plates, is to be found in the manufactories of the calico-printers. They employ copper plates for printing their calicoes. In these instances, the copper plate is first engraved, and bent round so as to form a cylindrical roller, and then the two edges are soldered. By contrivances the die is placed by other rollers into the hollow of the engraving, when the calico to be printed passes under the roller by the force which the roller itself exerts from the revolution imparted to it by a steam-engine. In this way twenty or thirty yards of calico can be printed in a few minutes. These copper plates might be either multiplied before they are bent, or afterwards, upon the same principles that plain electrotype copper plates are made. There would be no great difficulty to make a perfect copper roller without any solder, should that be a desideratum to the manufacturer.

The unlimited multiplication of copper plates by electro-metallurgy, opens a question of curious interest; for however beautiful the design of any work may be, however perfect its execution, if it is always before our eyes it ceases to have a pleasing effect. Who ever saw a ploughman admiring the brilliant petals of a buttercup, and yet what work of art is equal to it? In this case, however, the object is far more common than any work of art possibly could become, and, therefore, probably but little analogy exists between the two cases. Those print-sellers who allow but a limited number of any engraving to enter the market act foolishly; for if the design is really excellent, it would be impossible to render it so common that every individual in the whole range of civi-

lized nations should cease to admire it. The more perfect the work the greater extension will it bear; therefore, let those who engage in these arts seek rather to produce a perfect work and an extended circulation, than several imperfect engravings with but limited circulation. Engravers who are desirous of obtaining not only the necessary means for present subsistence, but also a laudable and permanent reputation, should cause a relievo of their work to be executed and deposited in some national collection, as with but moderate care such a cast would last from generation to generation.

CHAPTER IV.

ON THE MULTIPLICATION OF STEEL PLATES.

(267.) Steel plates can only be copied in a peculiar manner. They must not be placed either in the sulphate, nitrate, or muriate of copper, as certain destruction would ensue. I have heard of steel plates being thus destroyed, and therefore I particularly dwell on the fact to prevent its repetition. The crystallized acetate of copper is not decomposed by steel, though after the galvanic current has been passing for some time free acid is left, which is apt to attack the steel. A steel plate, however, undergoes no change in an alkaline ammoniuret of copper, ammonio-sulphate, or ammonio-nitrate of copper. From these salts, therefore, the copper may be thrown down upon the steel, but I am afraid that no advantage can be taken of the fact, as the reduction of copper by

these means is attended with considerable difficulty. Under these circumstances, we must have recourse to other methods of making a relievo duplicate from a primary plate of steel. This may be done in either lead, wax, plaster, or any other substance on which we can obtain a perfect cast, and from this a copper plate can be again made in the same way.

Besides these modes of making a relievo from a steel engraved plate, I have yet another plan to propose, which is even far superior to any yet detailed, and which, on that account, must supersede every other mode. This process of multiplication, which is so excellent, consists in first making a reverse in silver, and lastly, a second reverse in copper, which is used at once for printing. To effect this object, the steel plate must be carefully cleaned from any adherent grease, and allowed to remain in a cold place twenty-four hours before using it. A strong solution of argento-cyanide of potassium must then be procured and placed in a stoneware or glass vessel. A piece of silver connected with the platinized silver of a battery should be next placed in the solution, and the size should be about the same as that of the steel plate. The last operation is to immerse the steel plate itself, which must not be effected before it is connected with the zinc of the battery. The process should be continued till the silver is sufficiently thick for removal, which operation must be performed in the usual manner. There are, perhaps, no processes in the whole range of electro-metallurgy more easy than this; for the silver may be obtained of excellent quality, and not the slightest adhesion will be found to exist between the original and duplicate; even the absolute polish of a highly-burnished surface will not suffer any injury from such a proceeding.

It is hardly necessary to mention that this process is applicable to steel dies, punches, and every other kind of article, as no greater difficulty would ensue in conducting the operation.

The only detriment to the formation of a silver relievo, is the expense of the metal, which in large plates would be considerable; perhaps, in some cases, that might be diminished by giving a layer of copper; otherwise we must be careful, as soon as we have formed a second reverse of copper, to re-melt our silver, and take especial care to suffer as little waste of metal as possible. The process, except in the great value of the silver, is profitable from the equivalent of silver being high.

(268.) Before I bring to a conclusion a description of the method by which duplicate copper plates can be obtained from primary plates either of steel or copper, I think it necessary to mention, that metallic plates may be multiplied not only by voltaic, but also by mechanical means. This latter method has been in use for some years, and was devised by that original mechanic, Mr. Perkins, who obtained a patent for his invention. The apparatus he employed may be described generally in a few words: he first engraves on soft steel plates, and then hardens them. From the intaglio impression of the device he obtains a relievo impression on a circular roller of soft steel, by employing an immense pressure on the roller as it revolves. The circular roller which has the drawing in relievo is then hardened, when any given number of printing plates can be made from it, in a very short space of time, by placing a plain plate under the roller, and causing the roller to revolve whilst under an immense pressure.

Some difficulty arises in performing the operation, for if it is continued too long, the fine work is injured; if too short a time, the deep portions are not sufficiently indented.

(269.) The duplicates by Mr. Perkins' process are never such perfect copies of the original but that engravers can tell one from the other, on account of an apparent imperfection in the plate, which requires the plate to be touched up. It is needless to add, that this immediately destroys absolute

identity. The duplicate obtained by electricity is perfectly identical with the original plate, and no engraver can tell the original when both are placed before him. However, there is one circumstance which is very singular, namely, that the duplicate or second plate gives a more beautiful impression than the original. This variation does not arise from any difference of tint, for this depends more on the printer than the plate, and is technically termed the pull. In fact, a copper-plate printer can print the same plate of several degrees of shade, depending upon the quantity of ink which he leaves in the work. The beauty of the duplicate over the original, perhaps, is to be attributed to the superior quality of the copper, which gives a better tone to the impression, for certain it is that every electrotype is slightly superior to the original plate.

Some years ago an attempt was made to print from stereotype copies of engraved plates. A plaster cast was made from the original, when a stereotype copy was formed in the usual manner; but the process failed not from a want of accuracy in the duplicate, but from the circumstance that the alloy of lead was found not to print clear like the copper or steel originals.

CHAPTER V.

ON THE MULTIPLICATION OF WOOD-CUTS.

Design on wood-cuts, 270. Process, 271. Conclusion, 272.

(270.) Civilized nations ought to regard the first application of wood-cuts with peculiar veneration, as they seem

to have suggested the idea of printing. At the present time, however, wood-cuts demand especial notice, on account of the beauty of their execution; for they have now been brought to such perfection, that in minuteness and sharpness of drawing, I have seen specimens which fairly rival steel engravings. They might appear not often to require multiplication, because it is almost impossible to wear them out; 10,000, 20,000, 50,000, nay, even 100,000 impressions, have been taken from one wood block. Still, however, a duplicate in copper is frequently required for various purposes. Wood-cuts are somewhat the reverse of copper-plates; for in the latter, the print is obtained from the ink left in the hollows of the plate, but in the former the design is the most elevated part, and the impression is printed from the ridges.

(271.) Surface printing seems to have been very little employed till the fifteenth century, at the conclusion of which, it reached a high style of perfection, the cuts of Albert Durer, as well as those of his contemporaries, being much esteemed for the beauty of their design and execution. After that period the art began, strange to say, again gradually to decline, and was nearly lost, when the genius of Bewick, at the conclusion of the eighteenth century, gave a fresh stimulus to this important branch of art, and from that period it rose to its present unrivalled excellence. The superiority of surface over other kinds of printing depends upon the facility with which the former operation of printing is performed, and the comparative indestructibility of the design.

For the multiplication of wood cuts and other analogous designs for printing surface blocks, Electro-metallurgy is useful in a variety of ways. Cuts that are used for a variety of purposes, as the arms of the sovereign, where many persons design a separate block to print, the type-founder usually has the design cut in wood. This is coated at the back and edges with wax or grease, black-leaded, and immersed in the solution of copper in the usual way, so that an intaglio copper

mould is produced. This mould may be used to make copper reverses, which are at once ready for the printer; or it may be used as a die to form clichée casts. The adjoining woodcut of the arms of his Royal Highness the Prince Albert probably cost, in the first instance, about two guineas, but the clichée (which was given to me by Messrs. Thorogood and Besley) would not be sold for more than a few shillings.

The time that such a clichée would last is very great, for since it has been in my possession nearly 10,000 impressions have been printed from it without its being in the slightest degree impaired.

In many instances, especially from moderate sized woodcuts, a clichée reverse is at once taken from the cut. At present there are few in England that are trusted with the performance of this operation, and I believe that only Branston practises it as a profession. From the annexed cut, designed

by the younger Landseer, a lad twelve years of age, whose rising genius will doubtless some day place him at the top of his profession, a clichée mould was first taken, and then, from the clichée, an electrotype duplicate, which, as in every

case where an electrotype is wanted for surface-printing, required the back to be coated with solder, or fastened to a block of wood to render it thick enough for fixing with the other type. The above cut I am enabled to give through the kindness of Mr. Longman, the clichée was executed by Branston, and the electrotype by De la Rue. Valuable wood-cuts, however, are but seldom permitted to have clichées taken from them, for fear any mischance or injury should ensue to the original. In these cases, a reverse of the original is formed in plaster, white wax, &c.: the former, however, being much to be preferred. An illustration of this mode of proceeding is given at the commencement of this volume. In this cut a sufficient thickness is given by a layer of metal at the back. My readers are altogether indebted for that beautiful illustration to the kindness and extreme liberality of Mr. De la Rue. The design was originally engraved for the back of playing-cards, and it is an interesting fact that in early times this was one of the first purposes for which woodcuts were ever employed. The first packs printed with this device were graciously accepted by Her Majesty and the Prince Albert. In this instance the original die has not been used, and will last for an unlimited time, as it is only the electrotype copies that have been employed for printing.

The multiplication of wood-cuts has been far more extensively carried on by Messrs. De la Rue, than any other firm. Their manufactory is reckoned by those most competent to form an opinion, one of the most complete specimens of the union of art and science in mechanics, physics, and chemistry, that this metropolis, or, perhaps even the entire world, can boast. The electrotype department occupies but a trifling nook in their vast establishment, and is used for the multiplication of the surfaces they employ for printing. Engaged extensively in the printing of every kind of ornamental and fancy stationery, they have a vast number of designs they find convenient to multiply by the electrotype, and perhaps at

their establishment the value of electro-metallurgy in the department of surface-printing is better seen than at any other manufactory.

Electrotypes for surface-printing are found to be even preferable to the wood itself, as not only is the copper far more durable than the wood, but even the cupreous surface is found to print more beautifully.

Electro-metallurgy promises to lend an important aid for printing surfaces generally, as an unlimited production will allow of the use of illuminated letters similar to those which graced the works of former years. There is but one obstacle to a great improvement in this department of the arts by electro-metallurgy, and that is the insecurity which the founder experiences in the absolute right to his productions; for if he incurs a great expense and executes a splendid design, as soon as he sells a duplicate he is liable to have the design pirated, when perhaps his original outlay will not be sufficiently covered. As soon, however, as more stringent laws are made to protect particular designs, every printed book will doubtless show the benefit of electro-metallurgy.

One of the most beautiful series of specimens of printing from electrotypes is to be found in an illustrated edition of "Thomson's Seasons," all the woodcuts of which were carefully preserved, and the actual printing performed from electrotype copies.

In no application of electro-metallurgy is the value of the science more conspicuously shown than in a mode of producing surfaces for printing lately patented and called by the patentee Glyphography. This branch of art was invented by Mr. E. Palmer of Newgate Street, and forms an important feature in the general illustration of printed works, and on that account demands particular consideration. The term Glyphography has been given by Palmer to this invention to signify that the original drawing itself is at once engraved, requiring no copying, and in fact scarcely any in-

struments, except those with which the artist makes his design. The mode in which so extraordinary an end is accomplished, appears ridiculously simple when it is detailed. The most essential part of the process is to make all the surfaces for printing as flat as possible, and for this purpose a plate of copper as used for engraving is first procured. This is blackened with the sulphuret of potassium in order that the draftsman may be enabled to judge of the effect which his drawing would produce, as he proceeds with his work. This blackened plate is warmed, and then coated with a compound of burgundy pitch, white wax, resin, spermaceti, and sulphate of lead, previously fused together. This composition, which is nearly white, must be uniformly spread over the plate, and the thickness should be about the one-thirtieth of an inch. The plate is now ready for the artist, who cuts through the white composition completely down to the blackened copper, and in fact with the exception of that precaution makes his drawing in the usual manner. In the selection of tools the artist should be guided by the manner in which they can completely and clearly cut out the composition; for it is important to make a clear indentation and not to turn aside the coating and leave a burr. A simple hook fixed in a wooden handle, a hook filed away on one side which most effectually cuts away the composition, or a piece of wood tapering to a fine point, are the forms particularly recommended by Palmer. The former instrument is best adapted for very fine lines, the second for larger lines, and the last for foliage and other free drawings and designs.

When the artist has finished his drawing, the parts of the composition which are removed leave black lines, which have precisely the same relation to the white ground as the black lines in the subsequent print have to the white paper; so that a most important feature in Palmer's operations is the exact similarity between the design and the print.

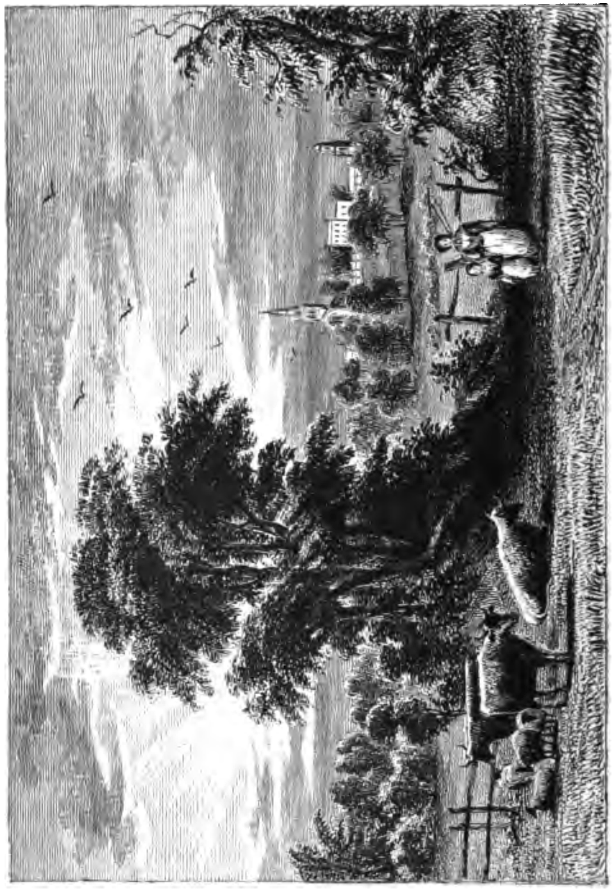
The plate upon which the design is drawn in the manner

already sufficiently detailed is then sent back to the patentee to be treated differently, according as the artist desires an electro-glyphographic cast, or a stereo-glyphographic cast from which to print. If an electro-glyphographic cast is desired, and this is always to be preferred for very delicate and highly-finished drawings, the high lights are built up with any non-conducting substance, in order that they may not print. Where, however, the work is much thicker this process is not required, as the interval between the lines not being so great the depression between the lines need not be so deep. The plate is then placed in the metallic solution and an electro-cast is taken in the same way as in duplicate copper-plates, &c. As soon as this is finished, the back is soldered and mounted upon a block of wood or to a piece of metal. The block is at once ready for printing, and with the modern improved system of overlaying now adopted by wood-cut printers, the print is an exact copy of the original drawing. If the artist desires a stereo-glyphographic cast, Palmer takes a cast of the artist's drawing in plaster, when he cuts out the parts corresponding to the high lights, a procedure which has the same effect as building up the lights for an electro-glyphographic cast. In this plaster-cast any little white lines may be inserted, which were not cut in the first design. This cast is then oiled, and a second taken from it, which second is sent to the stereotyper's to have a stereotype impression made. This is then ready for the printer in the same way as the electro-glyphographic cast.

For the adjoining view of Highgate church which is a specimen of this new branch of art, my readers are indebted to the kindness of Mr. Palmer, and though but an early specimen of this important invention there is but little doubt that the effect and delicacy of touch there displayed, points out the high perfection that it will ultimately attain. Cross-hatching in future can doubtless be executed with all the beauty of line engravings and yet with all the facility of common drawings.

In cases where stereo-glyphographic casts are required, they can be delivered to the printer within forty-eight hours of the drawing being sent to the patentee, thus doubtless it will form a very important addition to typographical resources.

SPECIMEN OF PALMER'S PATENT GLYPHOGRAPHY.



VIEW OF HIGHGATE CHURCH.

The expense of glyphography being the same for the commonest and finest productions, the value of the art in a pecuniary part of view is most apparent when the design is elaborate, and for very common cuts the present mode is

to be preferred, for it appears that the expense of such cuts would be less than the new mode; but it is said that map-engraving will be so readily executed in this way as to allow the introduction of surface maps whenever they may be required. The expense hitherto of executing surface-printing maps is so great as to prohibit their introduction, and the inconvenience of introducing copper-plate engravings into the text is so great as to limit their use.

Such are the principal features of Palmer's Glyphography, and when thoroughly brought to perfection, there is but little doubt that its good effects will be felt by every person who either reads or writes, or even looks at pictorial representations.

We have yet another branch of art to describe, which is an invention called the electro-tint, which may be described in a very few words. A plain copper-plate is procured, upon which the artist makes a painting with some substance insoluble in the solution of sulphate of copper. The plate is placed in the solution and a reverse made, which is at once ready for the printer.

A great many specimens of the electro-tint, prepared by Palmer, who has a patent for the process, have been published at different times, and of various degrees of excellence, but the best that I have seen is a small portrait of Lance, by himself. There is something very pleasing in this print, and it shows at what perfection the art might eventually arrive. Sometimes the electro-tint cast is used to print from the hollows, at others from the elevations: thus, in one case it forms a kind of engraving, at another a surface similar to that of a wood-cut.

(272.) The different cases in which electro-metallurgy is serviceable for the various departments of printing have been now described, and it appears to me that the general name of electrotype ought to be restricted to these cases; for, although the propriety of the term when thus employed cannot be doubted, yet an extension of its use for dissimilar purposes is

certainly inaccurate. The electrotype, therefore, I consider as one of the subordinate branches of the general science of electro-metallurgy; though, doubtless, as the importance of the art of electrotypes for our manufactures is extremely great, so also its interest is increased from its being the first department in which the electric fluid has ever been used extensively to further the manufactures of the country.

CHAPTER VI.

ON MULTIPLICATION OF THE DAGUERREOTYPE.

Value of the electro-metallurgy for the Daguerréotype, 273.—Process for obtaining the duplicate, 274.

(273.) Papers and periodicals from time to time have contained accounts of the multiplication, in copper, of these splendid works. The success, however, which has attended these operations, I am afraid has not been so great as has been reported. From my own knowledge, I have but little to narrate upon the subject, and this has been confined to the observation of two plates multiplied in this manner. The image on the copper duplicate of one was moderately distinct; but it did not become visible till it had been exposed to the sun's rays. In this case, there was nothing left on the original plate, nor was anything visible in either till exposed to the light. On the original, however, the image never returned; but the plate was uninjured, and therefore might be employed again. The second plate was a duplicate in cop-

per from a plate of Dover Castle, executed by Dr. Simon, of that town, who also informed me that the image did not appear for some time. His view on this plate is more faint than that in the first plate, which is further increased by the reflection of the copper being nearly the same at the places where the image is, as where there is no device. There is, also, the peculiar appearance on the plate which is technically called "the curd." Dr. Simon informs me, that the impression will bear rubbing when it is apparent, but that the copper deposited upon a great number of plates had not the faintest trace of any view upon it. In one of these cases, the image was transferred from one plate to another rather than multiplied, because there was no increase of images, the image on the silver being only removed to the reduced copper, leaving the original plate quite plain and polished. In the other original plate, however, a faint image was left.

Electro-metallurgy seems to be useful for the Daguerréotype in other ways besides the multiplication of the image, as sometimes a thin layer of gold is deposited, which fixes permanently the image, and gives it a peculiar tint. Perhaps, it might be a good plan to platinize or iridiize the plate, as the impression might then appear black and white.

(274.) The process for the multiplication of the Daguerréotype is similar in all respects to that detailed for the multiplication of plain plates. Dr. Simon used the single-cell apparatus; but I believe that the battery will be found the best adapted. The film of air so often noticed must not be forgotten for the Daguerréotype.

It is necessary here to call the attention of my reader to the fact that notwithstanding Monsieur Daguerré was liberally rewarded for his invention in his own country, and France proudly vaunted her liberality in giving his discovery to other nations, yet a patent is taken out in England, which renders it illegal to apply it without the especial licence of the patentee!

BOOK THE SIXTH.

ON GALVANIC ETCHING.

(275.) All our previous operations have been conducted at the negative pole of the battery; but at the positive pole certain effects take place which may be taken advantage of in the arts. Let us call to mind the fact, that gold, silver, and all metals with a greater affinity for oxygen, are dissolved when made the positive pole of a cell charged with a solution of the same metal. Now the relative distance which is maintained between the positive and negative poles affects the degree of solution which takes place. This property may be easily shown by attaching a wire by one of its ends to the silver of the battery, and placing the other in a solution of sulphate of copper in the bottom of which a piece of copper connected with the zinc of the battery is immersed. After a short time, the wire will begin visibly to be dissolved, and the part nearest the negative metal will be affected; this will go on till the wire is dissolved, in such a manner that the part nearest the negative metal will diminish to the sharpest point, and the different amount of action will produce a perfect taper.

(276.) Although this property is of no value in its application, yet I have introduced it to show the facility with which the copper in every place is dissolved exactly in proportion to the electricity passing: and this is likely to be extremely

valuable for engravers in their etchings. The term etching, is given to those engravings where the lines are not cut by any instrument, but are dissolved out by an acid. In order to make an etching, a copper plate is first to be prepared by covering it with a substance which protects it from the action of the acid in which it has to be immersed. The substance used for this purpose is composed of asphalte and wax in equal proportions, combined with a fourth part of both black pitch and burgundy pitch. This mixture is placed in a piece of silk, and rubbed over the copper plate, which is kept at a moderate heat, by holding it over a lamp or chafing-dish. This operation is technically called laying a ground; this at first is colourless, but it is afterwards blackened by holding it over the flame of a candle, and depressing it till a copious supply of smoke covers the surface.

The engraver, with an instrument like a needle, called an etching point, executes his drawing, and in so doing removes the ground, and exposes a clean surface of metallic copper. The plate is then placed in a dish, and dilute nitric acid poured upon it, till the copper is dissolved out from the exposed lines to a sufficient depth. The plate is not allowed to remain in the acid a sufficient length of time to bite deeply, as this would cause the engraving to be of one degree of blackness; but after it has been in the acid a short time, those parts which are required to be of a light shade are stopped out, that is, they are covered with brunswick black, or a coat of varnish capable of resisting the action of the acid; the plate is then re-placed in the dilute acid, after a time it is again removed, and a farther portion is stopped out; and these operations are repeated as many times as there are differences of shade required in the engraving. The degree of perfection that the professed engraver obtains by practice is truly extraordinary, considering the uncertainty which must attend the operation; for the action of nitric acid is not subject to any regular laws, and moreover is never

alike over all parts of the same plate. This is owing to the copper plate itself being never pure; but always containing tin, dispersed here and there throughout its texture, which resists the action of the acid. After a splendid plate is bitten in, some portions are sometimes left which cannot be acted upon by the nitric acid, but absolutely require the graver to bring up the fine lines.

(277.) No engraver that I have conversed with, can explain the cause of these faults in their work, but to the chemist they are perfectly intelligible; the nitric acid attacks the copper, forming a soluble nitrate of that metal which is dissolved in the fluid; but the action of nitric acid on tin is altogether different, for it converts the metal into a peroxide, which, being insoluble, protects the copper from the acid. The engravers have always noticed this white powder, (the peroxide of tin,) so fatal to the success of their operations.

(278.) Etching by galvanism is a far more certain operation than the foregoing, because it can be reduced to known principles. In this case, the plate to be bitten in has the device first drawn upon the same ground that is used in the ordinary process; the back and edges of the plate are then coated with wax, and it is to be connected by means of a wire with the silver plate of one or two of my batteries.

The size of the negative pole of copper, I stated in my former edition, should be as large as the positive or etching plate, but subsequent experiments have proved that to bite with greater regularity and sharpness, the relative size of the two plates should be as dissimilar as possible; for that purpose, a fine wire should be preferred, and when an equal depth is required, should be equidistant from every part of the plate.

The piece of copper to form the negative pole should then be connected to the zinc, when both the copper plate and the piece of copper are to be placed in a solution of sulphate of copper. Immediately copper will be reduced from the solution on the

negative plate, and copper from the etching plate will be dissolved to keep up the strength of the solution.

Whatever is favourable to the increase of electricity, causes the copper to be more quickly acted upon, and whatever diminishes the galvanic current, retards the solution of the metal; the nearer the etching plate forming the positive pole, and the piece of copper forming the negative are approximated, the more rapid will be the action. In the same way, the intensity of the battery also affects the rate at which the plate is bitten in. The negative plate of copper, however, should not exceed in size the copper-plate on which the etching is executed, or else there is a risk of some of the lines being more deeply bitten in; and in like manner, if any considerable part of the plate has a great deficiency of lines compared with other parts, that part must be stopped out rather before the other, to ensure a uniformity of depth, or else the negative copper opposite this part must be bent in such a way as to increase the distance.

(279.) The advantages of galvanism for etching, are, the absence of poisonous nitrous fumes, which are evolved in the ordinary process; the greater uniformity of action which takes place than when acids are used, and the rapidity of biting which may be regulated to the greatest nicety. The lines may be made of any depth, and are sharper and cleaner than when acid is used; and lastly, no bubbles are evolved, which the engraver well knows are apt to tear up the ground, or to cause unequal action.

(280.) The exact quantity of copper dissolved from the plate, can be ascertained by weighing the metal reduced on the sheet of copper which forms the negative pole, or by measuring the quantity of hydrogen evolved from the silver plate of one of the platinized silver batteries; for thirty-two grains of copper will be dissolved for every forty-eight cubic inches of gas evolved.

Etching by galvanism can be executed with any desired degree of rapidity, according to the series of batteries to which the plate is connected; but I believe that the practical man will find that the action should neither be too slow nor too quick, and perhaps two or three batteries, arranged as a series, will be found best adapted, though a single cell would suffice.

(281.) Galvanism would be valuable to the engraver for executing gradations of shade, such as, for instance, the effect of a strong light illuminating a whole room. The most simple manner in which this can be shown, is to take a copper plate and draw a number of lines on the ground with a ruling-machine. The plate, after having its back and edges coated with any non-conducting substance, should be then connected with the silver of the battery, and copper wire. These two should be then arranged in the solution of sulphate of copper, that at one end they nearly touch, while at the other they are widely apart. By this position, the greatest quantity of electricity would pass at that part of the plate where it is nearly in contact with the negative pole, whilst the least would pass at the opposite extremity. The action on the etched plate being exactly in proportion to the quantity of electricity passing, is unequal over the whole length of the plate, being greater where the metals are nearest, and gradually diminishing to the other end. This is the most perfect mode by which it is possible to obtain a gradation of shade. Many variations in the arrangements might be made by using, as a negative plate, a wire or a rod of copper, placed over the centre of a prepared plate; for then a perfect gradation would be obtained, extending in all directions from the dark centre. In the same way, two or more radiating shades may be obtained, by using two or more negative wires. An insensible gradation might be made from the darkest shade at the external edge of the plate, to the lightest

point at its centre, by cutting out a hole in the negative piece of copper, opposite to the part where the transition into light is required.

(282.) The professed engraver who once practically masters the galvanic method of etching by the theoretical principles which I have here detailed, is sure to obtain great results. He could execute with ease the most extraordinary transition of light into darkness with fidelity, and with the utmost certainty. However, I trust that the value of electric etching will not be confined to the artist; for, by removing the disagreeable consequences attending the use of nitric acid in the present mode of etching, more persons may be induced to enter into it, and, by this means, numbers studying the sciences will be enabled to execute an etching of those objects which are curious and rare, to send to their brethren who are studying the same subject. Those travelling in foreign countries, or in picturesque situations, might transmit to their distant friends an idea of the sublimity and grandeur of the scenery which they are enjoying, or of the appearance of the towns and villages through which they are passing. In fact there is not a person who might not be benefited by receiving etchings from others, and who might not, in return, circulate engravings of those objects which he may see. Pictorial representations are avowedly better than any verbal descriptions, so that there is ample scope for any one to exercise his talents usefully; and certainly many cannot be aware that etchings are not more difficult to execute than common pencil drawings. The process is as suitable for ladies to practise in their drawing-rooms, as are any of their usual amusements; the operation being attended with as little trouble. It is necessary at first to have the plate prepared, or have a ground laid, (which might be done by a workman,) and at the conclusion of the drawing it has to be bitten in. The objection to this, hitherto, has been the disagreeable properties of the acid, as it is likely to spoil clothes or injure furniture; but now that these objections

are removed, I trust that numbers will enter into this amusing and useful branch of art.

Mr. Grove has lately extended this process for galvanic etching, to the etching of Daguerréotype plates. He arranges the silver plate as the positive pole in a trough, by connecting it to the negative plate of a battery. He employs the silver plate about the same size as the Daguerréotype; but, I believe, he would find that he would be able to bite much deeper by following the improvements in galvanic etching described in a former part of this chapter. It is stated that these etchings when printed showed extraordinary minuteness of detail.

CONCLUSION.

I have now detailed briefly, but I trust usefully, the properties of bodies which are called galvanic, and the effects which galvanic batteries produce, as far as relates to the interesting subject of electro-metallurgy. Our science, even in itself, is essentially dependent upon galvanism, and the precipitating apparatus employed is nothing but a battery cell. With regard to the laws regulating the metallic deposit and the metals capable of being deposited by the voltaic current; these are derived from my own observations. The importance of these laws to the operator, will be to enable him to proceed with certainty. The reason which has induced me to devote so much labour and thought to these laws, has arisen from a conviction that the electrotype must have been abandoned unless the operator could proceed upon certain fixed principles. The extension of the few isolated facts formerly known, and their enlargement into a general science will, I trust, be found useful to those engaged in prosecuting these operations.

The influence which this new science will have on the arts, manufactures, and commerce, of our great country, it is scarcely possible to foresee. The extended use of galvanism for manufactures requires the utmost encouragement, and the improvements must not be shackled by patents, if we desire the scheme to succeed; for the ingenuity and the talent of the whole country is required to place it upon a firm footing.

The multiplication of copper-plates will cause a far greater demand for them than has ever existed heretofore, and the engraver need be under no apprehension; for not only will his talents be more required, but he will be called upon to execute more splendid specimens of art; for as these can be multiplied *ad infinitum*, a large circulation will render it worth while for any publisher to pay a very high price for an original which he conceives will meet with great public approbation. The publisher, in the same way, could lessen the price of engravings from our finest works of art, so as to bring them within the means of every person; and there is no doubt that he who first engages in a business upon the above liberal and well-known principles, will realize for himself a large fortune, and contribute greatly to the benefit of society.

For our potteries, the multiplication of plates assumes a higher importance even than the last-described valuable applications; for it enables the manufacturer to improve the designs upon our otherwise perfect earthenware, and then all countries will indeed be jealous of what they are already otherwise inclined to look upon with envy.

Our calico-printers will also now be enabled to use far more costly plates than they have hitherto employed.

There are many other applications of this science besides those which I have already detailed; such as the capability of adding copper to copper, and other similar purposes, which cannot be effected by any other process. Another important application of galvanism is, the means which it is likely to afford of separating one metal from another, or from its ore.

This subject is so vast, that had I entered upon it, another twelvemonths would have elapsed before this work could have been printed. It appeared to me better not to incur this delay, especially as I hoped that the public would be benefited by receiving at once the laws and principles which have been detailed.

A great variety of the applications of electro-metallurgy may appear to many to be trifling, as they contribute only to embellish the drawing-room and gratify the eye; but let them remember, that if private persons engage in the manufacture of these little trifles, it will lead to a knowledge, and a practical knowledge, too, of the effects of one of the most important and universal agents operating in nature. If manufacturers engage in it, it will lead to a more general use of the galvanic battery, which doubtless will eventually hold an important place in our manufactures.

It is true that electro-metallurgy offers many opportunities for fraudulent proceedings, as by it the forger can copy, with ease and unfailing accuracy, any embossed surfaces or stamps, and therefore no embossed work whatever should be used where there is likely to be any inducement for copying. By it seals may be forged, and an impression may be taken off a copper plate if it only remain in the possession of the party for a few seconds; besides, our new science gives the false coiner many opportunities to further his fraudulent practices. These things are particularly pointed out to put people on their guard against the designs of bad men.

Science, however, must not stop because some of its applications are liable to be turned to bad account by the evil-designed; and we must recollect that those things which can be forged by the electro-metallurgist, can also be forged by other processes before known. It was a favourite maxim of our great countryman, Wollaston, that "whatever man can execute man can also copy," and therefore the very idea of any device being inimitable is absurd.

Of the value of electro-metallurgy to the arts and manufactures, even in the present state of the science, there can be no doubt. It is not now a question of probability whether this science is practically applicable or not, for we have detailed fully what has been done by its agency; we have given full descriptions of all the various processes for obtaining with certainty many results; and finally, we have arranged all the facts into a tangible and systematic form, and, by laying down laws by which all its operations are governed, reduced the whole into a vast comprehensive science.

It may be, indeed, a matter of conjecture, to what extent this science may be ultimately carried out, or to what other purposes it may be applied in years to come; but were it never to be applied otherwise than it has already been; were it to stop for ever at the point to which we have now brought it, no one can deny that it is a most valuable acquisition; in short, we may safely assert, that no other single discovery ever presented capabilities at once so many, so various, so interesting, or so valuable.

This science depends for its very existence on electricity; and among the indirect benefits which it may surely be hoped will arise from it, we may mention the study of electricity generally: of which gigantic power so little is known, and which plays so important a part throughout nature; for though all of us recognize its operation in the thunder-storm, and view with terror and amazement the devastating violence with which, at such times, it makes known its power; yet, at present, how little do we know of the effects which it is at all times producing around us by its silent and continued operation.

The science of electricity is perhaps one of the most sublime examples of the might of human intellect, for by its agency man has made obedient to his will a power capable of producing such vast and terrible effects. "*Nil mortalibus arduum est*," says Horace, when speaking of Prometheus, who was fabled to have stolen fire from heaven; and modern

science has proved again and again the truth of the assertion, though little could he have thought, when writing the passage, how nearly the fable of Prometheus would in after ages become verified.

To the young chemist, we would particularly recommend the study of this science, and should he be tempted to turn his attention to it in a systematic manner, he will be amply rewarded for his trouble. The results of his experiments are lasting, and will be contemplated by him in after years with pleasure; whereas chemistry, being too often used as a source of amusement, brings forth very different results. The experiments tend to nothing, and end in nothing, beyond the present gratification; they illustrate facts which have been illustrated exactly in the same way a thousand times before, and are usually selected to be gone over and over again, purely because they possess some incidental character which is calculated greatly to astonish the uninitiated spectator, though not to enhance the scientific acquirements of the operator. By such a course of proceeding (for undoubtedly such it very commonly is) nothing is done, either directly by the operation, or by increasing the knowledge of the operator, and there remains nothing to show for the labour and money expended, except perhaps, the trouble of clearing away the remains, or, what is not so easily accomplished, the rectifying of the mischief done to furniture generally. We have no hesitation in saying, that electro-metallurgy will afford as much or more gratification as an intellectual pursuit, and infinitely greater satisfaction in its results.

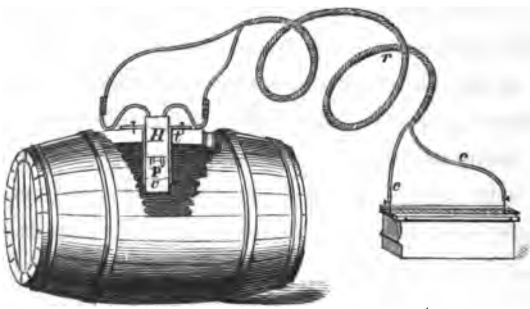
In conclusion, we cannot too often impress upon our readers the advantage of making themselves thoroughly conversant with the principles upon which the operations of electro-metallurgy depend, and the laws by which these operations are in all cases governed. By hurrying at once into the performance of the various processes without thus qualifying themselves, what can be expected but failure and its conse-

quences, disappointment and mortification? Proceeding in ignorance of the rationale of the process, untoward circumstances are for ever marring the designs of the operator; experiment follows experiment, and failure follows failure; materials are expended in vain, and, after the loss of much time, the student (if such he can be called) becomes tired of a science which has yielded him so little satisfaction, and throws it aside in disgust, perhaps attributing its uncertainty to that which is the pure and absolute result of his own idleness and consequent ignorance. But if the student proceed in an orderly and philosophic manner, making himself first acquainted with the nature and *modus operandi* of the materials with which he is about to work, he cannot by any possibility fail in his results. With such preparation no casualty can occur which cannot be readily referred to its true source, and consequently as readily remedied. Those who are comparatively unacquainted with electricity and galvanic apparatus may meet with some little trouble in entering upon the science of electro-metallurgy; but commencing upon a right method, their first trouble will be their last; and let them always bear in mind, that without trouble no great good was ever accomplished.

There are purposes besides electro-metallurgy for which the galvanic force is applicable to the wants of mankind, and of the most conspicuous of these is the mode of blasting in mines and under water now adopted. This beautiful idea was first put in practice by Lieut.-Gen. Pasley, who I believe was the first who adopted the system of blowing up vessels under water in this country. Whilst engaged in operations on the river Thames, he was written to by Mr. Palmer, who recommended him to employ the galvanic battery instead of the long fuse then in use. After having been shown in what manner the Voltaic battery was applicable to his wants, he instantly adopted it, and has since turned it to such account in the removal of the wreck of the Royal George, that his name will long be remembered from the universal satisfaction which his

proceedings have caused at Spithead. He at first used Daniell's battery, but when I visited the lighter, he had abandoned the professor's battery, by giving up the essential part, the sulphate of copper, and simply using sulphuric acid; but what battery he at present employs I am unable to state. Lately, Captain Fisher, the Harbour-Master of the river Thames, has removed the wreck of a collier off Gravesend. The nature of the proceedings which Captain Fisher adopted I am enabled to give with more minuteness, which will serve as a guide for others requiring similar proceedings. The barrel in which the powder is

Fig. 37.



placed had a hole bored in it, so that it might admit a copper tube (*t*). This copper tube had a plate soldered to it at the upper part by which it might be fastened by copper nails to the cask; a plug (*H*) was fixed in the tube, through which two copper wires were inserted, and round the end of the wires was wound a fine piece of platinum wire (*p*), so that but a single filament extended from wire to wire, the rest of the tube was filled with fine powder, and a piece of cork (*c*) was placed on the other end. This copper tube was then carefully secured water-tight by smearing pitch round the copper. For securing the tube and wires in their place, the ends of the two copper wires were bent and nailed to the tub. The next thing was to fill the tub with blasting-powder by another hole, and then secure the aperture water-tight with a wooden plug,

which was afterwards smeared over with pitch. The cask was then lowered to the bottom of the vessel, and placed in the situation where it was destined to act. A rope, previously made by procuring two wires first covered with cotton and varnished, and twisting them with the texture of which the rope is made, was then lowered to the bottom of the sea, and the ends of the two wires communicating with the tube were tightly lashed to the two wires in the rope. All these things being ready, the ends of two wires at the other extremity of the rope were connected with the two extremities of a small compound platinized silver battery, when immediately on contact being made the explosion took place.

The galvanic force is also now employed for telegraphic and other purposes, of which a description would here be given if it did not require a too great extension of the work. I have been compelled, however, to introduce the mode of blasting, from the frequent inquiries made about it, and the great benefit which the process affords to the operator, by diminishing materially the risk of accident to those engaged in mining operations. The great advantage of galvanic blasting is dependent on the source of heat not being applied till the moment it is wanted, and then being instantaneous; whereas, in the former modes of proceeding it frequently takes place after it is expected, when the workman imprudently approaching to see the cause of the delay is instantaneously mutilated or destroyed. The employment of galvanic batteries in mines, ought to be peremptorily enforced; for but a few batteries would suffice for the largest mine, and as the immersion in the liquid need not be longer than half a minute for each explosion, the charge of acid would scarcely require to be changed once a month, and consequently but little destruction of zinc would ensue. The battery might be fixed to some secure situation, and the workman would then only have to move the rope to the spot desired.

Doubtless the galvanic fluid will, before long, be as impor-

tant to the manufacturer as the heat of a furnace. At present a person may enter a room by a door having finger-plates of the most costly device made by the agency of the electric fluid; the walls of the room may be covered with engravings, printed from plates originally etched by galvanism, and multiplied by the same force; the chimney-piece may be covered with ornaments made in a similar manner. At dinner the plates may have devices given by electrotype engravings, and the salt spoons gilt by the galvanic fluid. All these, and many other applications, we may have at present, but we must still look forward to the most important properties of the electric current derived from the galvanic battery; for although great and glorious are the triumphs of science detailed in this work, yet the prospect of obtaining a power which shall supersede steam, exceeds in value all these applications. For to cross the seas, to traverse the roads, and to work machinery by galvanism, or rather electro-magnetism, will certainly, if executed, be the most noble achievement ever performed by man.

APPENDIX, No. I.

ON ELECTRO-METALLURGICAL PATENTS.

THE statute of Monopolies, (21 J. 1, c. 3,) declares the conferring on any person the exclusive privilege of carrying on a particular trade, or manufacture, to be altogether contrary to the laws of this realm, and a species of offence, called monopoly. The statute, however, excepts Letters Patent for the term of 14 years, and under, for the working or making of any manner of new manufactures within this realm, which others at the time of making such Letters Patent shall not use.

A new manufacture may be the production of a new article for the first time, or a new mode of producing the same article either by an addition or omission of any part of the process, or, with regard to chemical patents, of some new specific process. A new manufacture may also consist of a new application and adaptation of some known agent or thing.

It is essential that any of the above manufactures or processes should be a new invention "as to the public use and exercise thereof;" in other words, no patent is valid that is taken out for inventions in public use, although the practice in secret, of any process by a manufacturer will not prevent another manufacturer from taking out a patent for the same process, and forbidding the first. The prior publication of a process in a printed book in this country, under certain circumstances, will vitiate a patent, though a process well known and freely practised abroad may be patented in this country. The new manufacture, in any case, must be useful to entitle it to a patent; therefore, the slightest novelty attended with great good will justify a patent.

For the inventor to secure to himself the exclusive right of a new manufacture it is essential that he should disclose his

process in such a way that persons may use the same at the expiration of his patent; and the spirit of the English law seems to suppress monopoly, but to allow advantages, for a limited period, to those who benefit their country by adding or introducing any new and useful manufactures.

The principle which guided our forefathers upon patents deserves the highest commendation, though the practice of their successors upon this subject cannot well be worse; for, as now constituted, Letters Patent cause great expense to inventors who really deserve them, great injury and trouble to manufacturers from their being frequently granted where not deserved, and endless expense and litigation from their insecurity when obtained. If the principle of patents according to the English constitution were strictly adhered to in practice, nothing could more tend to improve and enlarge our manufactures.

The establishment of a court of scientific men to determine upon the amount of novelty in any invention, of another of manufacturers to decide upon the utility of the novel parts, and finally, the submittal of their decisions to a court of law to consider whether the presumed invention or introduction was entitled to a Patent, and for how long such patent should be granted, would, with well-arranged details, be enabled to carry out our ancient laws in the letter and spirit; for, by reducing the expense of the patent, affording greater facility for procuring it when deserved, preventing the possibility of its being granted improperly, and rendering it, when obtained, an absolute protection, the inventors would be directly benefited, the manufacturers protected, and the prosperity of the whole country would be enhanced by the monopoly, in the manner that the wisdom of our forefathers contemplated.

From the preceding observations, the Electro-Metallurgist will perceive that it is not only essential that a patentee should have a patent to secure the monopoly of any manufacture, but that he should have acquired it properly. For this reason it is by no means certain that the following patents

are rightfully possessed, and therefore it would be wise in a person interested in any process to examine carefully how far any patent interfering with his business is valid. The following list I have principally compiled from the "Repertory of Patent Inventions" and "Newton's London Journal," particularly valuable sources of reference for these matters; and in these journals, especially the last, tolerably full extracts of a great number of electro-metallurgical patents have been given.

There is a curious point of law connected with some of these patents, and that is, particular processes have come into public use between the granting of a patent and its specification; and which processes could not even be inferred in the slightest degree from the title of the patent. In these cases, common sense, doubtless, says that the patent ought not to prohibit the manufacture in common use; but what the law says lawyers alone can decide. Persons requiring information on this subject may consult a chapter dedicated to these matters in Stephen's Commentaries on the Laws of England, book ii. part ii. chap. 3, or a very interesting little treatise by Webster, "On the Subject-matter of Letters Patent by Invention," the author being a great authority on these points.

If a true and valid patent is infringed, the inventor has his remedy by an action of trespass for injury sustained, and he may also obtain an injunction to restrain the continuation of the manufacture, and can compel the aggressor to deliver an account of the profit he has derived from the sale of the article. Moreover, any person using the name or mark of the patentee is subject to a penalty of 50*l*. The action may be resisted by showing that the patent is void in the manner already pointed out, or the patent may be formally impeached (if improperly obtained) in the Queen's name by the Attorney-General, or even by any other person with his consent.

The first strictly electro-metallurgical patent was granted to James Shore, of Birmingham, merchant, for improvements in preserving and covering certain metals and alloys of metals.

Sealed March 3, 1840. Enrolled in the Enrolment Office, Sept. 1840. The patentee claims the coating of manufactured articles of wrought or cast iron, lead, and copper, and its alloys, with copper or nickel; such coating being effected by galvanic electricity.

The next patent was granted to George R. Elkington and Henry Elkington, of Birmingham, for improvements in coating, covering, or plating certain metals. Sealed March 25, 1840. Enrolled in the Enrolment Office, Sept. 1840. The patent is for numerous processes of gilding, plating, &c., &c.

The next patent was granted to Thomas Spencer, of Liverpool, carver and gilder, and John Wilson, of the same place, Lecturer on Chemistry, for certain improvements in the process of engraving on metals by means of voltaic electricity. Sealed Oct. 7, 1840. Enrolled in the Petty Bag Office, April, 1841.

A patent was granted to Joseph Lockett, of Manchester, in the county of Lancaster, for certain improvements in manufacturing, preparing, and engraving cylinders, rollers, and other surfaces for printing and embossing calicoes or other fabrics. Sealed August 27, 1840. Enrolled in the Petty Bag Office, February, 1841. This appears to be an important patent connected with the cotton printing manufactures.

A patent was granted to William Tudor Mabley, of Wellington-street, North, in the parish of St. Paul, Covent-garden, in the county of Middlesex, mechanical draftsman, for certain improvements in producing surfaces to be used for printing, embossing, or impressing. Sealed Dec. 17, 1840. Enrolled in the Rolls' Chapel Office, 1841. This patent seems to contain numerous applications of electro-metallurgy to printing-surfaces, but to what perfection he carries out his processes I am unable to state.

A patent was granted to Alexander Jones, engineer, for improvements in the manufacture of copper tanks and vessels. Sealed June 14, 1841. Enrolled in the Enrolment Office, May, 1841.

To George R. Elkington and H. Elkington, of Birmingham, for improvements in coating, covering, or plating certain metals. Sealed June 22, 1841.

To Edward Palmer, of Newgate-street, gentleman, for improvements in producing printing-surfaces, and in the printing of china, pottery, vases, music, and maps. Sealed June 12, 1841. This patent is briefly noticed under the head Electro-tint in the text, and a little work dedicated to this subject has been written by Sampson.

Specification of the patent granted to Islam Baggs, of Cheltenham, gentleman, for improvements in printing. Sealed Jan. 23, 1841; enrolled 23rd, 1841. This is a very ingenious patent, whereby colours are given by means of the galvanic battery.

Ogilthorpe Barratt, of Birmingham, metal-gilder, for certain improvements in the precipitation or deposition of metals. Sealed Sept. 8, 1841.

W. H. Fox Talbot, of Laycock Abbey, Wilts, Esq., for improvements in coating or covering metals with other metals, and in colouring metallic surfaces. Sealed Dec. 9, 1841.

Edward Palmer, of Newgate-street, philosophical instrument maker, for improvements in producing printing and embossing surfaces. Sealed Jan. 15, 1842. This important patent has been described under "Glyphography" in the text, and an illustration is given.

H. B. Leeson, of Greenwich, Doctor of Medicine, for improvements in the art of depositing and manufacturing articles by electro-galvanic agency, and in the apparatus connected therewith. Sealed June 1, 1842.

Edmund Tuck, of the Haymarket, silversmith, for improvement in the covering or plating with silver various metals and metallic alloys. Sealed June 4, 1842.

J. S. Woolrich, of Birmingham, chemist, for improvements in coating with metal the surface of articles formed of nickel, or metallic alloys. Sealed August 1, 1842.

APPENDIX, No. II.

ON THE INTIMATE RATIONALE OF THE VOLTAIC FORCE, COMPRISING THE UNITY OF THE PROPERTIES OF MATTER, AND PROBABLY OF ITS COMPOSITION.

Our work on electro-metallurgy is now concluded, and we have found extraordinary operations performed by the electric current. Whence arises this current? How is it produced? For most practical purposes we find at the present time that the voltaic battery furnishes exclusively the power that is turned to such good account in the arts. But what is a voltaic battery? Such a question may occur to every child, but would greatly puzzle the sagest philosopher. If we examine my new definitions of the voltaic phenomena, we see that they are certain effects between two points; the abstraction of the first element of an electrolyte, and the evolution of the second. From that definition we may learn that a galvanic battery is such a contrivance, apparatus, or combination of an electrolyte and some substance decomposing it, in such a way that the interval between the two points is extended to a tangible length. I have little hesitation in asserting that this definition has been of the greatest advantage in my own experiments, since the idea first occurred; and, doubtless, if it had preceded instead of following my electro-metallurgical experiments, I should not have incurred so much loss of time, waste of materials, and useless expense. But in this definition there is nothing contained that can possibly satisfy the enquiring mind as to the nature of the force, or show whence it comes, whither it goes, or how it is set in motion. Let us take a galvanic battery—my own in

preference, from its simplicity—and endeavour to discover the cause of the actions there going on. The battery we know is made of platinized silver and zinc, in metallic connexion with an intervening electrolyte of dilute sulphuric acid. The point of abstraction of one element is at the zinc, the evolution of the second element at the platinized silver; therefore we may have the voltaic phenomena manifest themselves either in the liquid between the plates, or in the zinc and silver plates, completing the circuit between the parts immersed in the fluid.

Before we begin to analyse the changes that occur, we should dismiss useless ingredients. We shall, therefore, leave out of consideration the silver and dilute sulphuric acid, their purposes being of secondary importance, the silver for the removal of the second element, the acid for the withdrawal of the oxyde of zinc. We have now but two substances remaining, zinc and water, and we find that we can obtain power by the action of the zinc and water, till the zinc has combined with every portion of oxygen in the fluid. If we try the experiment with zinc and water alone the action would require a long time, because we should continually be compelled to scrape off the oxyde of zinc. If we use sulphuric acid instead of the mechanical scraping, it will only assist us to a certain point; for at last it will cease to dissolve the oxyde, and then we shall be in the same difficulty as before. We find, therefore, that in a galvanic battery there is a continual change in the arrangement of the elements of the electrolyte; that some new body is formed by the subsequent combination of one element, whilst the second element is manifested in a free state, to be removed in the easiest possible way.

Having proceeded thus far, we are led to examine the relation of the manifestation of power to this change in the fluid, and we find that the one is exactly proportionate to and synchronous with the other. We find, moreover, that we may have a tendency or a desire to produce an effect, but yet no

voltaic effect without the absolute passage of the current into the same trough from whence it came. The electricity must have existed in the trough before the action commenced, because the effects are quite independent of any external agency, and one equivalent of electricity is manifested for every equivalent of water decomposed. There can be no production of electricity in the trough, because as soon as the circuit is completed no excess of electricity appears; but everything is as quiescent as it was previous to action: the only difference to be observed being, that instead of one compound we have another.

If there is no production of electricity there is certainly a motion of it, and it is the electricity in motion that produces all the wonderful effects. At first sight we might run into error, from a consideration of the above facts; for we might suppose that the voltaic battery is simply an apparatus, whereby the electricity naturally inherent in one compound is transferred to another compound; thus we might be led to suppose that the actions are as follows:

Before action.	At the moment of action.	After action.
$Z \quad \overset{E}{\overline{OH}} \; \overset{E}{\overline{OH}}$	$\overline{ZO} \; \overset{E}{\overline{HO}} \; \overset{E}{H}$	$\overset{E}{\overline{ZO}} \; \overset{E}{\overline{HO}} \; H$

Such a view of the question naturally pleases from its beautiful simplicity, and, because it is as suitable to the double as to the single electric theories. But there is a manifest imperfection in the hypothesis; for it gives no reason or cause why the zinc should take the oxygen from the hydrogen; and, moreover, we cannot see how the electricity could have got into the water in the first instance, for we can make that compound by the direct union of its elements without any addition of electricity. We are, therefore, compelled to consider that the electricity exists in all elementary bodies, and from such a supposition, we must examine the cause of the motion of the electric fluid in the galvanic battery.

All particles of bodies either have electricity in some way

adhering to them, or attached to them in an extraordinary manner, which we are unable to determine; or they seem to have the power of inducing electricity between each other under certain circumstances. All particles of bodies seem to be held together by that principle; for we are acquainted with the manner in which it can set loose elements in combination, or make them take other new combinations or conditions. Whether there be two electricities or one electricity, I cannot now consider; but the term negative may be applied by either theorist to negative, as usually considered, or a relative deficiency of electricity; positive to positive, or an abundance of electricity. The state of electricity in the primitive portion or atom is, doubtless, a state of quiescence; but as soon as two primitive atoms approach each other, the electric equilibrium would be disturbed, the two particles (O) would first have a tendency to repel each other, but as speedily, by an induction long since well understood, would cause opposite electricities (NP) or states of electricity to be set up in the contiguous portions, and attraction will be the result.

Before action.	After action.
E E	NP NP
O O	OO

Such an attraction existing between the particles of like nature would satisfactorily account for crystallization, and even for all the peculiarities which crystalline bodies present. The well-known varieties of forms which the same substance presents might arise from differences in this inductive state; for a vast number of atoms being arranged together, and the inductive influence being excited from each one to all the rest, the mass would be held together by the complex forces that would be produced; and if these forces were exerted at different parts in different degrees, how perfectly can we account, and perhaps eventually even calculate, the different amount of force with which the atoms of a crystal are held together in certain directions, and

perhaps eventually turn it to good account in the cleavage of these remarkable bodies! The attraction of aggregation would differ from the attraction of crystallization by the forces being exerted between pieces of the same substance, of irregular forms, instead of the ultimate particles of bodies; the irregularity of the form in the first instance presenting an obstacle to a thoroughly close apposition of the particles.

Like weights of different elementary bodies do not appear to contain the same quantity of electricity, because the amount which would set free one grain of hydrogen would liberate 108 of silver. This question might be viewed in two lights; either that the amount of electricity, naturally adherent in the ultimate particle of a body, is dissimilar (that is supposing that atoms are all of the same weight), or that the ultimate particle or atom of a body differs in weight, and that each ultimate particle is endued with the same amount of electricity. Either view would appear to account equally well for all the phenomena. The weight of the atom might regulate the equivalent of electricity, or the equivalent of electricity might regulate the combining or equivalent number of the substance. Perhaps, however, after studying the effects of proximate elements, it would be far better not to assume that electricity adheres to a body as an integral part of it, for electricity is a principle, a property, and not a material substance; on this account we are compelled to state that an equivalent proportion, or ultimate atom, always induces the same amount of electricity upon the atom, or equivalent proportion of every other substance.

The different conditions of bodies may be satisfactorily explained by differences in the attractions: thus solidity would show a more intense attraction between the particles, than fluidity, and fluidity again than vaporization; thus far greater force would be required to remove one pound of ice from a mass of that substance, than a pint of water from a stream, which latter operation would require more force than the removal

of a pint of steam from a steam-boiler, and we shall, in treating of the identity of heat with electricity, show how these states are dependent on that latter agent. The attraction which bodies exert on each other may be termed their weight, although that term is usually referred to the attraction exerted between the earth and smaller bodies in its vicinity. The principle which regulates weight is usually called gravitation, which is precisely similar to the other attractions we have before mentioned. The attraction of gravitation may be neutralized by every other kind of electrical attraction, and is materially altered in intensity by the effects which electricity is capable of exerting on matter. From these considerations, the specific gravity, being the intensity of electric attractions exerted upon a certain bulk of any body by the inducing power of the earth, must eventually lead us to a knowledge of a law, whereby the force with which the ultimate particles of elementary bodies are held together, or even the force with which any two bodies are kept in combination, may be known. At present it grieves me to say, that although apparently very near this important truth, it has not been my good fortune to determine it with accuracy.

We have already considered the state of elementary particles, in which we have determined that the electricity is quiescent; but we must now determine its state when the particles have entered into combination, and we shall find that this would vary under different complications of arrangement. When two atoms are simply joined together, it is apparent that two excesses of electricity will manifest themselves at the outer sides: thus the outside of one atom would be negative, the outside of the other positive, whilst the two inner halves would be alternately negative and positive. In such a state oxydes and chlorides would exist. Such a combination is termed a proximate element, and differs from ultimate elements by their electrical excitement. However, three elements might be joined together in different ways, either

in such a way that the whole of the electric tensions are neutralized, or so that the excitement might demonstrate itself.

In the former case the direction of the forces would, probably, form an equilateral triangle, the angles being at the centre of each atom. In the latter case, however, the three elements might be arranged in a row, and then at either extremity the positive and negative excitements would exist. Such instances might, with great propriety, be called neutral, or excited proximate elements, according to circumstances. If the same elements can, in electric conditions, unite themselves in such a variety of ways, isomerism ceases to be an extraordinary phenomenon; and the many different properties evinced by organized bodies of nearly similar or even of identical chemical composition, is perfectly explicable. A good example of an excited proximate element is seen in ammonia of a neutral in cyanogen.

Four atoms, five atoms, six atoms, or even many more may be arranged together in a manner similar to the three atoms; that is, they may be arranged as an excited proximate element, or a neutral proximate element.

We have now arranged all proximate elements into two classes, excited and neutral. The excited having at the extreme ends opposite electric tensions, the neutral having no external tension, all the tensions being opposed to contrary states within themselves. Excited proximate elements will combine freely with excited proximate elements in two ways, either the negative end might be attached to the positive of the other, or the negative and positive of one might be arranged so as to neutralize the positive and negative of the other; thus, muriatic acid and oxide of potassium might be arranged longitudinally or one over the other.

We may infer that the combination of two or more excited proximate elements generally produces a compound more firmly held together than what is accounted for by the attraction

between the elements of the single proximate elements of which it is made up, because in the combination all the tensions are increased. Hence the nitric acid in nitrate of potash is far more difficult of decomposition than nitric acid alone, &c.

Atoms of neutral elementary bodies in close cohesion, have the properties of excited proximate elements, and from this cause resist combination with other neutral elements in the direct proportion to the force with which the atoms are held together. Hence arises the facility with which metals combine when in infinite division, and the obstacles they afford to the same combinations, when in the reguline form. When the tension induced by two neutral elements is greater than the attraction of cohesion of one of the elements then combination ensues.

Excited proximate elements can combine but very feebly with neutral elements, because the electric induction of opposite states could but slightly take place. Muriatic acid could not well combine with potassium, or hydrogen with the oxide of potassium. Perhaps, however, the feeble combinations of alkalies and chlorine with their analogues, are of the latter class of compounds; for a vast difference is observed between the intensity of combination of the chloride of calcium and chloride of lime, or of sodium and soda, &c.

Neutral proximate elements, however complex their composition, by being themselves made up of a great many ultimate elements, may combine with single atoms of a primitive element; and yet no more electricity would be induced between them than if two ultimate elements were united together. In these cases it is not improbable but that the amount of electricity is regulated by the primitive element, and, perhaps, even induced by it. I cannot call to mind that two neutral proximate elements unite together with any degree of firmness, and, therefore, having no fact am unable to reason upon the nature of such a combination.

Having seen that in chemical combinations the same amount of electricity holds together different elements, it becomes a curious question to ascertain how far the intensity of that amount is equal in all cases. Viewing the whole range of chemical phenomena, it appears tolerably conclusive that the tensions must vary considerably; because we find disturbing forces favour combinations, or effect decompositions with very various facilities. The tension holding together bodies in combination appears, in some cases, to be infinitely greater than similar tensions holding together bodies in adhesion, aggregation, solution, &c.; yet in other cases the attraction is so great as almost to prevent chemical union, as in the chorundum or diamond.

Heterogeneous adhesion, capillary action, &c., appear generally to arise from the attraction of opposite states of electricities of two elements, or compounds, in a state of excitation.

The solution of a solid by a fluid presents some difficulties from the complex nature of the phenomena which it presents. The attraction of solution differs from that of combination in several respects. Taking into consideration the whole range of the phenomena, it is possible that by the juxtaposition of the fluid and solid the tensions holding together the latter are neutralized or, perhaps, more properly speaking, counterbalanced; so that the solid is brought into a fluid state, and the two fluids coming together are condensed, producing a heat which helps the liquefaction of the solid. In some cases, however, the condensation does not produce sufficient heat to balance the deficiency always occasioned by the change of state, in which cases cold is produced.

There is a peculiar property in all the attractions which is called polarity, which literally means nothing more than that all the forces lie in the same direction. If we consider a mass of matter held together by the forces already discussed, how different would be its state if all the forces were in a line, or intersecting each other in every direction. Polarity being

absolutely essential to voltaic action, it is evident that a body, although in every other respect in a more favourable condition for the neutralization of its intensities would, without possessing a facility of arranging its forces in a polar state, afford an absolute obstruction to the passage of the force.

The manner in which elements are held together having been carefully considered, we are in a condition to examine the cause of the motion of electricity from the changes taking place in the voltaic battery. In the first place, the water is composed of two elements, hydrogen and oxygen, which are held together by an induction

$$\frac{\mathrm{PN\ PN}}{\mathrm{O\ \ H}}\ \frac{\mathrm{PN\ PN}}{\mathrm{O\ \ H}}\ \frac{\mathrm{PN\ PN}}{\mathrm{O\ \ H}}$$

the zinc is a primitive element, therefore neutral, but being held together by cohesion becomes excited. The arrangement if polar would be as follows: —

$$\frac{\mathrm{PN\ PN}}{\mathrm{Z\ \ Z}}\ \frac{\mathrm{PN\ PN}}{\mathrm{Z\ \ Z}}\ \frac{\mathrm{PN\ PN}}{\mathrm{O\ \ H}}\ \frac{\mathrm{PN\ PN}}{\mathrm{O\ \ H}}\ \frac{\mathrm{PN\ PN}}{\mathrm{S\ \ S}}$$

But the ZO inducing opposite attractions to the ZZ, OH, SS, a peculiar state is instantly induced. A great desire is manifested for the whole of the first tensions to be neutralized. The zinc cannot take the oxygen unless the means are afforded for the terminal tensions P and N of the first arrangement to be neutralized, whereby all the intermediate attractions are also destroyed; but as soon as the terminal tensions are united, then does action take place. According to this view of the case it is not essential that the attraction of ZO should be greater than OH, or even so much, provided it be sufficient to overcome the difficulties of imparting the new tension from one atom to the other; for if but a portion of the tension become neutralized, the tension would gradually lessen till it was extinguished, and therefore, a feebleness in the opposing tension or zinc would only demand an increase of the time necessary for the duration of the action. This is the state of

tension in the pile, or as it might more properly be called a desire for change in the induction. According as this state of tension is exalted, the greater obstacles will the terminal P and N overcome in order to unite, and as soon as they become united the whole of the former tensions are neutralized, and instantly the particles being in juxta-position take on new tensions, as follows:—

$$\frac{\mathrm{PN\ PN}}{\mathrm{Z\quad Z}}\quad\frac{\mathrm{NP\ NP}}{\mathrm{H\quad O}}\quad\frac{\mathrm{NP\ NP}}{\mathrm{H\quad O}}\quad\frac{\mathrm{PN\ PN}}{\mathrm{S\quad S}}$$

But we have now oxyde of zinc adhering to one end of the water, and hydrogen adhering to the other. The whole arrangement must now return to the state in which it first existed, by the removal, in some manner, of the oxyde of zinc and hydrogen, and the oxygen of the water must arrange itself in a polar state against the zinc.

In fact the entire former intensities are neutralized, and new ones are instantaneously induced. Such is the simple mode by which electricity appears to be set in motion in the voltaic current. Let us now trace its action to see the manner in which the electricity thus set in motion decomposes a compound body; for instance, water, the state of which may be thus represented:

$$\frac{\mathrm{PN\ PN}}{\mathrm{O\quad H}}\quad\frac{\mathrm{PN\ PN}}{\mathrm{O\quad H}}\quad\frac{\mathrm{PN\ PN}}{\mathrm{O\quad H}}$$

As soon as a current of electricity passes, the N coming in contact with P, the P with N, the induced electric states of the two terminal atoms are neutralized, and, in consequence thereof, all the intermediate atoms also lose their induced electricity and become neutral. The intermediate elements being in contact, simultaneously and instantly induce an opposite state of electricity, and again combine. The two terminal atoms of hydrogen and of oxygen at first having a slight adhesion between the poles do not combine with their neighbours, and afterwards not being in contact cannot combine, and therefore, are ready to be evolved or enter into

new combination with any substance that may present itself. The following illustration will serve to explain this change:—

E	NP	NP	NP	NP	E
O	H	O	H	O	H

It is not strictly correct to say that the two ultimate particles are in a neutral state, for there would be a slight state of tension between them and the poles. With regard to the relative facility of setting in motion this electricity, it is apparent that, as electricity between different atoms is always the same in amount but different in intensity, the electricity would be set in motion, *i. e.* the terminal electricities would join with an impulse directly proportionate to the intensity induced between the new element and the first element of the compound, and in the inverse ratio to the resistances afforded to their junction. Hence it would appear that zinc induces the same amount of electricity with greater intensity than copper, copper than silver, silver than gold, &c.

If we examine the effect of the addition of another excited element into the water,—for instance, potash or muriatic acid —it is probable that they assist the water to become polar, or arrange all these excitations in the same way; for we have already seen that after the removal of one atom of the oxygen the hydrogen would be against the zinc, and before action could take place the atom of water must turn round, so that the oxygen and zinc are in juxta-position.

The next circumstance which we have to consider is the mode of transit of the electricity through conducting solids. Solids we have mentioned are kept together by electricity in the same way as different elements in combination; thus we might consider our wires to be in the following states:

NP	NP	NP
Z	Z	Z

the particles of the metal being held together by the electric tension. If a positive electricity comes in contact with the negative it neutralizes it, and has a tendency to neutralize all

the tensions in succession if the opposing tension be sufficiently strong. Instantly, however, the same electric attractions will be induced, and the particles of metal would be again held together with a force proportionate to the intensity of the induction. Elementary conductors as wires, are identical in the manner of their resistance with that of compound fluid conductors, as the intensity of action would be directly as the new exciting intensity, and in the inverse ratio to the obstacle offered to the neutralization of the intensities of the terminal atoms of the wire. From the slight resistance offered to intensity by metallic conductors, we must assume that but little power is required to transmit the opposing intensity from atom to atom, and from that we deduce that the particles readily arrange themselves in a polar state, and are held together by a much less force than bodies in combination. The effect of the neutralization of the tensions in the solid part of the arrangement, enables us thoroughly to understand why silver and gold rolled are not acted upon freely in certain solutions, but at the moment of neutralization of the tensions holding together the particles of the metal, the atoms of the two different elements being in juxta-position, unite most freely.

Let us pause and consider this matter in reference to our equation. In the first place the desire for action or rather, perhaps, the power of neutralization of the first tensions, the (I), is proportionate to the power of electric induction evinced by the positive element of the pile (F), minus the sum of the tensions holding together the compound (r), the sum of the tensions holding together the connecting portion or the solid part of the arrangement (c). This is the first action; and we at once see, and see clearly, too, the cause of all the phenomena called voltaic. From such considerations the effect of extending any part of the circuit would materially lessen, if not entirely counterbalance the power of (F). The two other parts of the equation, the (a), and the (c), would not come into play till the second atom of water had to be decomposed, when we at once perceive that they would

present themselves as two foreign bodies in the circuit, and foreign bodies of a very imperfectly conducting nature; the nature of the resistance they would offer would be directly proportionate to their thickness and to the force with which their particles are held together. The difficulty of the passage of the force round a corner is clearly attributable to the peculiar polarity which that case would require, as probably there must be reflection of the tension to enable it to overcome that difficulty.

We have now traced the action of zinc upon the fluid, and zinc is only given as an example of what is termed the positive element of the pile; for the same reasoning applies to every other positive element. We must next examine the effect of introducing into our circle a new element which is not held together by electricity, or at any rate but very feebly. In such a state we expect to find the infinitely-divided metals constituting the black powder obtained by the first law regulating electro-metallurgy, and we shall see their action would be very remarkable; for as soon as the zinc has neutralized inductions between the particles and they have again become excited, the terminal hydrogen of the liquid would be in contact with the black platinum. But these bodies are not capable of inducing electricities of tension between them so strongly as particles of hydrogen do to hydrogen; the consequence is, that the neighbouring particles of hydrogen unite into bubbles and rise to the surface of the liquid.

The atom of black platinum, moreover, is not in a state, perhaps not sufficiently close to induce much tension with the neighbouring atom of silver, so as to assist this action, but if the platinum be rolled and prepared, so that the particles cohere, then does the attraction between the particles of platinum facilitate greatly the attraction between the particles in contact with the hydrogen and this latter element, when the hydrogen adheres to the surface of the metal. From such a view of the question, any substance in a state in which it could induce electricity, of but very feeble intensity with

the hydrogen or second element, would answer as well as finely-divided platinum. The following diagram will illustrate the above:

$$\frac{PN\ PN}{Z\quad Z}\ \frac{NP\ NP}{Z\quad O}\qquad \frac{NP\ NP}{H\quad O}\qquad \begin{array}{c}E\\H\end{array}\quad \begin{array}{c}E\\P\end{array}\qquad \begin{array}{cc}PN & PN\\S & S\end{array}$$

Metals in a state of cohesion favour the adhesion of the hydrogen by the intensities of the attraction of cohesion, whilst neutral elements or elements nearly neutral attract the hydrogen with a force proportionate to the induction between the elements and hydrogen, and as hydrogen generally unites to hydrogen with more facility than to infinitely-divided metals, evolution is the consequence.

In the case where the hydrogen is removed by new inductions, as in Daniell's and Grove's battery, the time occupied by such removal would be proportionate to the energy of the induction of the second element or hydrogen with the new substance; and the intensity of action to the time that such change requires to be effected. But if zinc takes the oxygen from the water, it appears singular that it should be capable of making such complex changes, instead of at once effecting that object. If indeed zinc and water only act on each other, the change is quickly effected: the zinc takes the oxygen, the hydrogen, having nothing to combine with, is set free. In this case, however, the hydrogen might slightly adhere to a neighbouring particle of zinc and lessen its action. The action without mercury would be the opposite tensions induced between zinc and oxygen, to that of the oxygen, hydrogen and same zinc, thus:

$$\begin{array}{cccc} & N & O & \\ N & & & P \\ Z & & & N \\ P & & H & \\ & P & & \end{array}$$

The action with mercury would be the opposite tensions induced between the zinc and oxygen to the previous tensions of the circle Z O H M. The mercury would not in the slightest degree stop the action of the first atom of zinc, but the new atom of zinc in combination or close connection with the mercury would have a layer of hydrogen interposed,

which would offer a great resistance; the circle would then be as follows: Z O H H H M. The hydrogen could not oppose any neutralizing effect inductively in an opposite direction to the power of the zinc; for this reason, the water can only be polar in one direction, and, therefore, whatever determined the polarity of the water would determine the course of the current: thus if the polarity of the water were in such a direction that the oxygen would be in juxta-position with the zinc, the hydrogen would be in juxta-position with the hydrogen, and then no opposing induction by the latter would take place.

If such be the true explanation of the employment of mercury, we must at once perceive that the mercury, is in every case a neutral element so excited by cohesion that the hydrogen may readily adhere, and therefore, any other neutral proximate element in the same condition would answer as well. Now it appears to me theory may be very interesting, but its great utility is to enable us to develope new facts; and, therefore, I immediately endeavoured to substitute for the mercury other bodies which I considered to be neutral proximate elements, and further took care to select them in such a physical state that the inductions might favour the induction of the hydrogen. Now oil of turpentine, sweet oil, and an immense variety of other similar substances, were tried with various success, as by these substances effects are obtained similar to amalgamation. In conducting these experiments, we are compelled to take especial care to cause these substances to adhere to perfectly clean surfaces of metal or else we are disappointed in the result.

In considering the nature of the voltaic phenomena, I have assumed the electric tensions at random, not knowing which end of the pile is negative nor which is positive. But I can from authority state that this matter is now known, and will be published as soon as the experiments are completed. This important addition to electric science is due to the indefati-

gable labours of Gassiot, forming another instance of useful and valuable services being performed by those who have apparently, from numerous other important avocations, the least time and opportunity.

Having now traced the manner in which the electric inductions cause crystallization, aggregation, cohesion, gravitation, chemical composition, &c., we might expect to be enabled to obtain electric action by different modes of interference with these various states. The electricity of aggregation we might naturally expect would be set in motion if aggregation itself were interfered with, and, accordingly, we find that by friction or pressure we can set in motion electricity. If we only consider that by pressure we can approximate the ultimate particles of bodies together, it is apparent to every philosopher that the electric induction would be interfered with; and this seems to be the kind of action, when polar, that is set up by the electrifying machine, and which might with great propriety be called the electricity of aggregation. Moreover, by heat we can effect the aggregation of bodies; it will appear, therefore, that thermo-electricity differs rather in its degree than in its source from frictional electricity, being really the electricity of aggregation. In thermo and frictional electricity we must, perhaps, assume a neutralization of the first intensities.

Magnetic effects are equally referable to electric inductions; for magnetism is a polar arrangement induced by electricity, and itself in turn inducing electricity. Magnetism is principally remarkable for its being in some respects an isolated fact at present; but, probably, every body or combination of bodies would exhibit the same phenomena, if we only knew the conditions most favourable to the continuation of the alternate arrangement of the tensions of the ultimate particles in a polar state.

Magnetic attraction appears to differ from other attractions by being only excited from iron to iron; but as heat may destroy magnetism, percussion either cause or destroy it, it is clearly an electric phenomenon; and the differences of the two

attractions are probably only those of intensity. The magnetic tension might be more easily neutralized than other tensions in the same way, as we shall hereafter see that the other attractions may be neutralized by heat, &c.

Electricity, with which every body, either by gravitation, by chemical composition, or by magnetic attractions, is held together, is clearly the cause of every form of heat with which we are acquainted. Heat is, indeed, one of the effects of electricity; and though we might by a fallacious reasoning be led to assert electricity is the effect of heat, a very slight examination will show the absolute futility of such a reasoning. In fact we have no heat of which the cause is known but that which is derived from, and proportionate to, chemical action, and therefore heat being rather a property of matter from chemical action, *i. e.* electricity, may, indeed, set electricity in motion, but cannot be said to be the cause of the parent from which itself has derived its existence. Heat (that is, an effect of electricity) being added to bodies held together by electricity, interferes with their electric attraction, either supplying new attractions or neutralizing old ones; if it is a solid body a small quantity first enlarges it and appears to neutralize some of its numerous electric inductions. A larger quantity makes it enter the fluid state, a state only differing from the solid by the particles being held together by a less force. A greater quantity causes the particles to be so feebly held together that they assume the gaseous state with various tensions, and a still greater quantity usually separates it into its component parts. How beautifully does our present theory account for the tensions of aërial bodies being proportionate to the heat required to give them that particular state! Moreover the specific heat of all bodies is the same for their equivalents. What further proof do we require of the identity of heat and electricity? and yet besides all these proofs do we not see electricity fusing the otherwise most infusible substances!

And wherefore is heat electricity and not light? we cannot

obtain light except from what we have already proved to be electric action. Light may arise from a disturbance of the electricity of aggregation, of the electricity of combination, of the electricity of magnetism ; and yet, let the student beware that there are not three electricities, but one electricity, which manifests itself as light. If we want further proofs of the identity of electricity and light, we need only look around and view the myriads of chemical and electric actions that light influences by retarding or advancing. Colours are nothing more than the quantity of electricity set in motion from each particle forming the substance, as the breadth of the tension regulates the colour.

The same arguments that apply to the identity of the principles of heat, light, electricity, magnetism, gravitation, crystallization, fluidity, vaporization, apply also to sound ; for who ever heard a sound without a chemical action, or a disturbance of the electricity of aggregation ? But sound appears to differ from light in the intensity with which its action progresses ; for we see the flash of the fatal cannon before the sound reaches the ear, and even before it has communicated its deadly blow.

Sound, then, appears to be a large quantity of electricity set in motion with a feeble tension, making a vast difference between it and light, which exhibits such immense intensity, though it seems to exceed the tension of heat which is communicated but to a very short distance. If nature is thus simple it might appear surprising that the theories of philosophers should be so complex ; but the fact could be as easily explained as the simplicity of nature, did not the already too great length of this volume warn me to draw it to a speedy conclusion.

If all these properties which I have examined at such length are electrical, what this electricity, this mysterious and universal principle is I have already pointed out. It is not a thing or material agent, and cannot be said either to enter

or leave any body. If it is not a thing, it is a property, and this property in light, heat, and especially sound, is manifested as a vibration.

Heat and light being only evinced during disturbances in the electric attractions, may be defined to be electric attractions in disturbance, and in proportion as anything assumes a comparative electric equilibrium cold is produced. Hence, in a perfectly calm and still night the thermometer will fall 40 or 60 degrees below the point at which it stood in the noon-day, when the electric attractions are all in such commotion from the sun's rays. The fall of the thermometer is proportionate to the calm and the absence of other objects, the electric induction between which might disturb its quiescence. From such a view how awfully cold would a single atom become, isolated from all other matters. All bodies being more or less in a state of continual electric disturbance, have a tendency to become equally disturbed; thus, if two bodies are approximated, differently situated in this respect, they become, after a short time, in the same condition.

Electricity of different inductions may be thus arranged:

			INDUCTION.	QUANTITY.
Electricity manifesting itself as		light	immense	very small.
"	"	sound	great	moderate.
"	"	heat	very small	immense.

If every kind of matter, elementary or compound, is only possessed of the power of setting in motion waves or undulations, and these waves are capable at one time of forming all the beautiful colours exhibited by the rainbow, at another, the thrilling notes of the happy nightingale, there can be no necessity for supposing a great variety of ultimate kinds of matter. Chemists, indeed, enumerate about sixty elements at the present time; but it is quite clear that the supposition of a single element, according to the present exposition of the properties of matter, would amply suffice; for if that single element were arranged in different manners, different electrical

relations, and, therefore, different properties would be produced: thus, 8 hydrogens arranged together might give a body having the property of oxygen; 108 hydrogens might form silver; 200 hydrogens gold; but we must remember that this is a theory possessing probability from the considerations of the properties of matter, yet by no means at present proved by direct experiment. But, although, it is by no means directly proved that there is but one element, it is equally unsatisfactorily determined that those bodies which we call elementary, have any right to that term; for cyanogen, sulpho-cyanogen, and a hundred other proximate elements would appear elementary, if the parts of which they are made up adhered so strongly as to resist decomposition. I have no hesitation in asserting that certain facts have come to my knowledge of particular cases, where two or three of the supposed elementary bodies have a strong probability of being made; but to bring forward so important a doctrine as an absolute fact would be altogether unwarrantable, without testing the observations in every possible way. It is not from these experiments that the idea of the unity of matter has been derived; but the hypothesis is rendered probable, by the supposition being forced upon us from the consideration of the actions in the galvanic battery. The idea of the unity of the composition of matter with unity of its properties; or in other words, of one element with one property, furnishes us with the most exalted notions of the power of the Creator. The very idea, indeed, is the sublimity of sublimity! for to consider all the objects that are daily exposed to view in this great globe to be made up of but one element, and under different circumstances to produce the infinitely varied, pleasing or painful, impressions would alone fill our minds with the deepest sense of the magnipotence of the Almighty; but if we consider not only that the great globe itself, but the moon, the stars, the sun, the universe might be composed of a single element obedient to one law, man must feel his insignificance, and catch a faint and

glimmering comparison between the attributes of the Creator and his created beings!

Student! we have done. Matter is active, not passive. Ponder well the identity of its supposed various properties. Remember, that the properties are electrical. Never forget there is but one Electricity. Consider the probability of unity of matter as inferred from unity in its properties; matter has but one property, and that property is manifested by its power of communicating a vibration—a wave.

ANALYTICAL INDEX.

Q.

R.

THE END.

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